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REPORT 312

AN INVESTIGATION OF OPERATIONAL DECISION AIDS

2 July 1977

Gary L. Lucas
Jan A. Ruff

Sponsored by
Office of Naval Research
800 N. Quincy Street
Arlington, Virginia 22217
Contract N00014-76-C-0877

ABSTRACT

In the Operational Decision Aids Program (ODAP), the Office of Naval Research is exploring the use of advanced methodologies--drawn from the fields of Decision Analysis, Information Science, Operations Research, and Organizational Analysis--to assist a task force commander and his staff in tactical planning and combat decisionmaking. In support of the ODAP, this report examines the problems encountered and the solutions realized in previous attempts to develop operational decision aids and decision aiding systems. Among the systems examined are the Vessel Traffic System (VTS), the Standoff Target Acquisition System (SOTAS), the TRIDENT Defensive Command and Control System, the Simulated Tactical Operations System (SIMTOS), the Navy Surface Ship Combat Directions System, and the Army Tactical Data Systems.

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CONTENTS

I. EXECUTIVE SUMMARY

A. BACKGROUND

In the Operational Decision Aids Program (ODAP), the Office of Naval Research is studying decision aids to assist a task force commander and his staff in tactical planning and combat decisionmaking. Emphasis in the program is on the exploration of methodologies--drawn from the fields of Decision Analysis, Information Science, Operation Research, and Organizational Analysis--to assess their applicability to support the task force commander in his decisionmaking role. The ODAP currently has prototype operational aids under development and a test bed under construction at the Wharton School of the University of Pennsylvania.

The aids under development in the ODAP will be integrated into tactical command and control systems, with initial implementation planned for the Navy's Tactical Flag Command Center (TFCC). ODAP will thus be confronted with many of the problems associated with the development of operational systems and with the incorporation of newly developed decision aids into an existing command and control structure. In order to minimize potential problems in implementing the aids and to develop efficient procedures for conducting the implementation, SPC was tasked to investigate previous attempts to develop operational decision aids and decision aiding systems. The investigation was to emphasize the problems that were encountered and the solutions that were realized in the development of operational aids. This report presents the results of that investigation.

B. APPROACH

The approach taken in the investigation was to examine a carefully selected set of operational decision aids and decision aiding systems and to illustrate by example the specific types of problems that were encountered in the development of the aids and the means that were found for resolving them. Emphasis in the selection of problems for detailed investigation focused on those which would be of greatest value to the ODAP in structuring their program. With the emphasis in the ODAP on the exploration of new methodologies, this requirement tended to favor the selection of problems that relate to the acceptance of the system by the users, although problems as diverse as those relating to the integration of a decision aiding system into an existing command and control structure and the structuring of the software packages for a decision aiding system were also considered.

In the investigation, attention was also given to the identification of procedures that successful system developers follow in developing their systems. An awareness of these procedures should be helpful to the ODAP in avoiding many of the problems commonly encountered in the development of operational aids. An attempt was also made in the investigation to obtain reasonably complete functional descriptions of the systems--both to provide the background necessary for an appreciation of the problems under investigation and to illustrate the character and level of sophistication of current operational decision aiding systems.

The principal systems examined in the investigation are:

- <u>The Vessel Traffic System (VTS)</u>. This system, developed for the United States Coast Guard by the Applied Physics Laboratory of the Johns Hopkins University, monitors vessels in San Francisco harbor and advises them of traffic conditions in the bay. It provides an illustration of a computer aided system that was developed to replace a manually operated, rudimentary system previously used for traffic control in the bay.
- <u>The Standoff Target Acquisition System (SOTAS)</u>. This system, under development by the U.S. Army Electronics Command, assists the division commander in making decisions concerning the deployment and utilization of his forces. It provides an illustration of an independently developed system that must be integrated into an existing command and control structure.

- TRIDENT/SSN Command and Control. The defense command and control systems of the Navy's TRIDENT and SSN nuclear submarines provide an illustration of the level of sophistication of present and proposed operational decision aids.
- The Simulated Tactical Operations System (SIMTOS). This system, developed by the Army Research Institute, is a research tool intended to assist in the development and study of computerized tactical command and control systems. It is tailored to the study of data base organization and processing, decision aid evaluation, and the more general problem of human-computer interaction in tactical C^2 systems.
- Navy Surface Ship Combat Direction Systems. These systems, which include the Naval Tactical Data System (NTDS), provide information to the tactical commander and his staff to assist him in maneuvering his ship and employing his weapons in a combat environment.
- Army Tactical Data Systems. These systems, which includes the Tactical Operations System (TOS), provide information to the division commander and his staff to assist him in preparing plans and making decisions concerning the disposition and employment of his forces.

Documentation on three other decision aiding systems was also reviewed in the investigation. The first two documents--a critique of the decision aiding system in the National Military Command Center and a description and historical profile of a mythical naval software system (MUDD)--contain discussions particularly relevant to the current investigation. The third--a report on the development of a decision aid to assist a tactical commander in attacking hardened air bases--describes an attempt to use Von Neumann-Morganstern Utility Theory in assigning tactical aircraft to an attack on a Warsaw Pact airbase.

C. DISCUSSION

The level of mathematical sophistication of the decision aids under development by the ODAP and the complexity of the activities they will perform substantially exceed the level and complexity of most presently deployed operational aids. Most operational aids are concerned either with the automation of procedures which were formerly performed manually or with relatively simple task aiding, such as the SOTAS aid that provides a time-compressed playback of data to assist an operator in visually detecting and tracking enemy activity (see Chapter III). More sophisticated aids--which permit, for example, a commander to explore the consequences of adopting alternative courses of action--are also operational (or near operational). A TRIDENT aid (see Chapter IV), for example, permits a commander to explore the consequences of adopting alternative tactics for a mobile countermeasure. The aid does not, however, possess the level of mathematical sophistication of many of the aids under development in the ODAP.

The introduction of sophisticated methodologies to assist the task force commander in the decisionmaking process, while offering the opportunity for substantial assistance to the commander, nevertheless, gives rise to critical problems involving the acceptability of the aids to the users. Some members of the operational community expressed considerable doubt that the approaches under consideration by the ODAP would be of significant value to them. Others felt that the introduction of such methodologies was premature; sufficiently challenging operational problems--concerned with, for example, the determination of what is appropriate to display and how it should be displayed--remain to be resolved before it would be appropriate to consider the use of methodologies of the type proposed by the ODAP (see, in particular, Chapter V).

The attainment of user acceptance for the ODAP decision aids is, in our judgment, critical to the success of the program. User acceptance impacts the opportunity for the aids to receive a fair and impartial evaluation within the community and ultimately the frequency and effectiveness with which the aids are used by the operators. Furthermore, in our judgment, it is an area that warrants considerably more attention than it is currently receiving in the program. Two steps that would promote the acceptability of the aids are:

- The methodology under development by the ODAP should be "sold" to the operational community on the basis of a demonstrated capability to assist the task force commander (or his staff) to make better decisions or to make them more quickly. To conduct this demonstration, the ODAP should develop near operational prototype decision aids. These should possess sufficient realism in the eyes of the user to provide a credible demonstration of the capabilities of the aids. In our judgment, this is the best--and quite likely a necessary--way to ensure that the decision aids are favorably received by the operational community.

- In developing the prototype decision aids, the ODAP should observe the principle of "methodology hiding" in structuring the aids. Methodology hiding implies that the interface between the system and the operator should comprise only displays and require only operations that relate directly and immediately to the combat environment in a way that an operator is accustomed to perceiving it. Requiring an operator to develop, compute, or interpret data or information that relate to an abstract framework with which he is not accustomed to working substantially reduces the likelihood that he will react favorably to the system and ultimately that the system will be successfully employed.

Other approaches that have been found in the development of decision aiding systems to promote the acceptability of the aids should also be pursued by the ODAP. Numerous examples of such approaches can be found in the body of the report (see, in particular, Chapter 2.) Certain of these--such as assuring the aids present an attractive physical appearance--are obviously desirable features to have in an aid, but frequently tend to be overlooked in favor of attention to technical details of the system. Others--such as assuring a decision aiding system can be easily learned and operated--require attention early in the design of the system. Each of these features, while primarily cosmetic in nature, is extremely important in gaining acceptance of a system; however, it is of such a character that it is often neglected by the theoretical researcher.

Other types of approaches, which are directed at ensuring potential opportunities for the rejection of a decision aiding system by a reluctant user, are minimized (see Chapter 2). System developers, for example, take great care to ensure that the initial operational version of a system performs satisfactorily. To lessen the impact of potential system failure, they provide "manual backup" for the system until it has been accepted by the users. They also take considerable care to ensure that adequate support capabilities--e.g., maintenance and documentation--are provided for the system.

Finally, and perhaps most importantly, the members of the ODAP should work closely and extensively with the operational community to ensure the understanding of the operational problems, to clarify the needs, and to develop the appreciation of the procedures and style of the operators necessary to successfully adapt the methodologies under study to the solution of the task force commander's decision problem (see Chapters 2 and 4). This step is particularly important for the ODAP, which must seek out applications for its methodologies and which must demonstrate the capability to deal effectively with the major functional problems confronting the operational developer in order to clearly demonstrate the efficacy of the methodology. Problems--such as the determination of what to display, how to display it, and how to integrate the aids with the existing sources of data--have not yet been fully addressed by the ODAP.

A variety of other issues are addressed in the report. For example, the integration of a decision aiding system into an existing command and control structure is discussed for SOTAS in Chapter 3. The type of problems encountered--such as the determination of appropriate roles for the system and the development of adequate measures for assessing the effectiveness of the system within the command and control structure--anticipate problems that are likely to face the ODAP. In the discussion of SIMTOS in Chapter 4, a simulation facility is described that in many respects parallels the test bed under development by the ODAP at the University of Pennsylvania. And in the final chapter, two issues are addressed that are important to the ODAP but that digress from the basic theme of the report. In the discussion of the MUDD system, attention is given to the software development problems that frequently arise in the development of decision aiding systems. And in the discussion of AHAB, an example is described of a preliminary attempt to apply sophisticated methodological techniques to a quasi-operational system.

II. VESSEL TRAFFIC SYSTEM

The Vessel Traffic System (VTS), developed for the United States Coast Guard by the Applied Physics Laboratory of Johns Hopkins University, monitors and advises vessels in San Francisco harbor of traffic conditions in the bay. VTS was conceived, developed, and implemented as a computer-aided automated system to replace a manually operated, rudimentary system that lacked the capability to successfully handle projected traffic in the bay. The concepts and associated hardware developed in VTS are now under consideration for use in other vessel traffic systems in U.S. coastal waters.

In this chapter we will stress the problems, solutions, and methods for avoiding problems that arose in the development of VTS. We will also stress the characteristics of the system, for we feel VTS provides an example of a carefully conceived system that emphasizes the needs and desires of the users of the system.

A. BACKGROUND

The vessel traffic control system which existed in San Francisco Bay before 1972 was generally recognized to be inadequate for safe and effective control of projected traffic in the bay. The system contained only one radar, which was located at Point Bonita near the entrance to the bay. In a hut adjacent to the radar, a television camera focused on a PPI display and transmitted the radar images to a control center located some distance away. Operators in the control center maintained radio contact with vessels in the bay and recorded the status of the vessels by means of a manual card system.

With the passing of the Ports and Waterway Safety Act of 1972 the Department of Transportation, through the U.S. Coast Guard, was given authority to develop, administer, and operate vessel traffic systems in U.S. port and coastal waters. Preliminary study of traffic conditions in San Francisco Bay by the Coast Guard suggested the need for a major new vessel traffic system. Moreover, it was concluded that a computer-aided system would meet the needs for vessel traffic control in San Francisco Bay and would potentially be useful for vessel traffic control in other coastal waters. As a consequence, a program was initiated with APL that led to the development of the Vessel Traffic System.

B. BASIC SYSTEM DESCRIPTION

The VTS is an all-weather, radar, communications complex which consists of: two surveillance radars with their associated adaptive video tracking equipment; traffic analysis and display computers; operator consoles; microwave radar relay links; ship-to-shore communications equipment; audio video and digital recording equipment; and operating personnel.

The VTS covers the area shown in Figure II-1. In the Radar region, coverage on vessels in the bay is maintained by surveillance radars at Point Bonita and on Yerba Buena Island. In the Vessel Movement Reports (VMR) region, which is not covered by radar, contact with the Vessel Traffic Center, located on Yerba Buena Island, is maintained exclusively by radio.

The VTS has both a manual and an automatic operating mode. Due to the absence of radar coverage in the VMR region, the operating procedures for each mode differ in the Radar and the VMR regions.

For the Manual Operating Mode in the VMR region, the procedures closely parallel those of the original vessel control system. On entering the region, a vessel reports its identity, position, destination, and desired route to the control center. An operator in the center records the reports on a Vessel Data Card and plots positions of the vessels on a large wall map. A separate card is maintained for each vessel, so that a record of its movements is available for review.

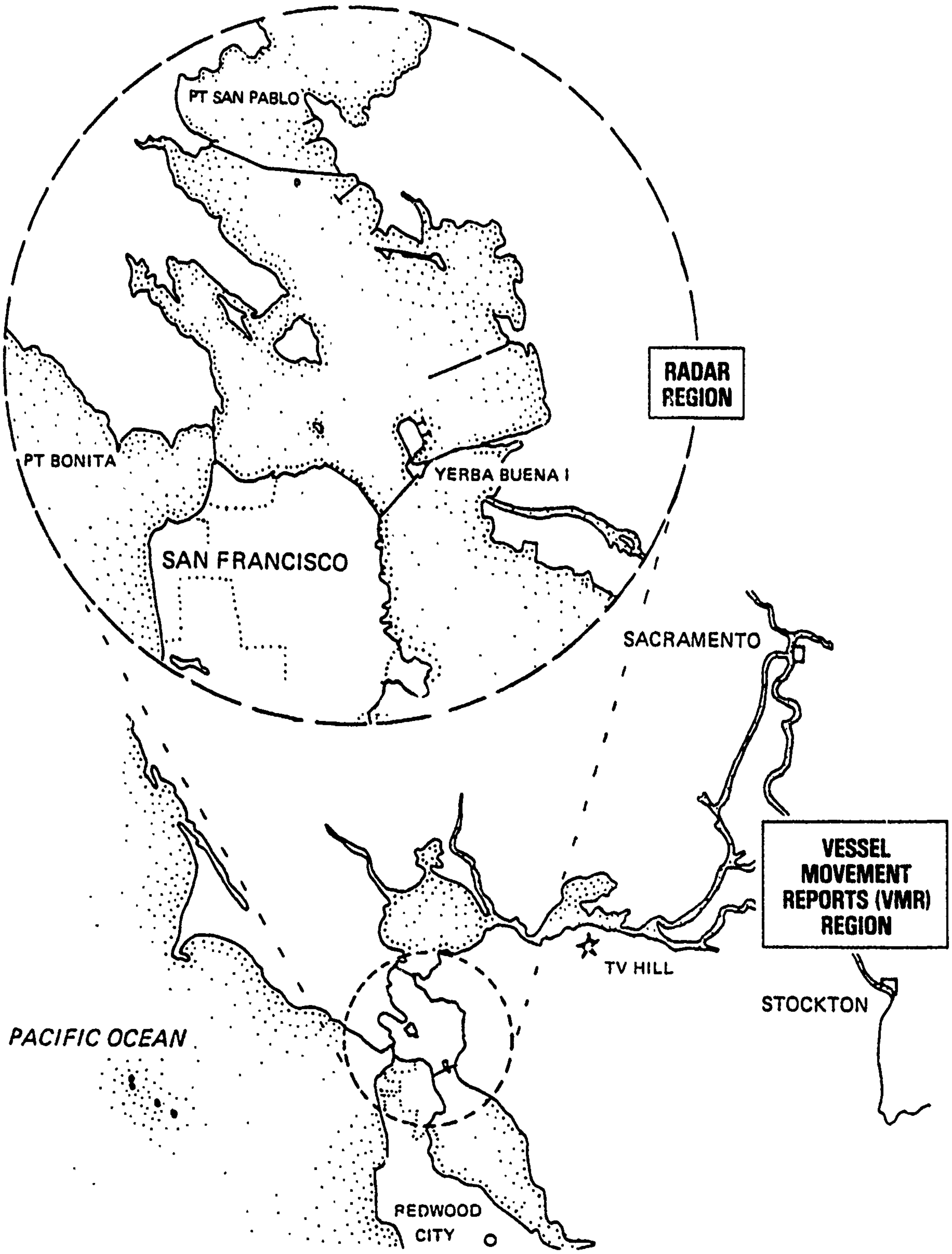

FIGURE II-1. VESSEL TRAFFIC SYSTEM SERVICE AREAS

For the Manual Operation Mode in the Radar region, the procedures differ from those in the VMR region in that the operator views the vessel traffic on a PPI (radar) display. As in the VMR region, the operator records the data for the vessel on Vessel Data Cards. He then tracks the vessels either on the wall map or directly on the PPI screen.

For the Automatic Operating Mode in the VMR region, the procedures differ only slightly from those in the Manual Operating Mode. An operator may enter data into the VTS computer via a keyboard at the VTS display console--to be described below--and subsequently retrieve the data to display the list of VMR vessels, including their names, positions, time of last report, and expected position and time of next report. If the next report is not received by the expected time, an automatic alert (alarm) is sounded by the system.

For the Automatic Operating Mode in the Radar region, the procedures make use of the full capabilities of the automated system. This system is composed of the Automatic Detection and Tracking (ADT) subsystem, one of which is associated with each radar, and the Traffic Analysis and Display (TAD) subsystem.

The ADT subsystem relieves the operator of the need to detect and track vessel traffic. By using adaptive detection thresholds keyed to the average clutter return in each area, the subsystem is able to automatically detect, classify, and track vessels in the bay. Tracks maintained by the system are classified as new, tentative or firm. For the firm tracks, estimates are made of a vessel's size, speed, and course. Up to 253 total tracks may be maintained per ADT, with an omission rule in the event of overload, which drops new and tentative tracks before firm tracks, and tracks for small vessels before tracks for large vessels.

The TAD subsystem accepts firm tracks from the two ADT subsystems, processes them, and then displays them for the operator. The display console for the subsystem is shown in Figure II-2. The Working Display is in the center of the figure with two satellite displays at the top. The keyboard and special feature controls--including the track ball to the far right--are shown in the lower half of the figure.

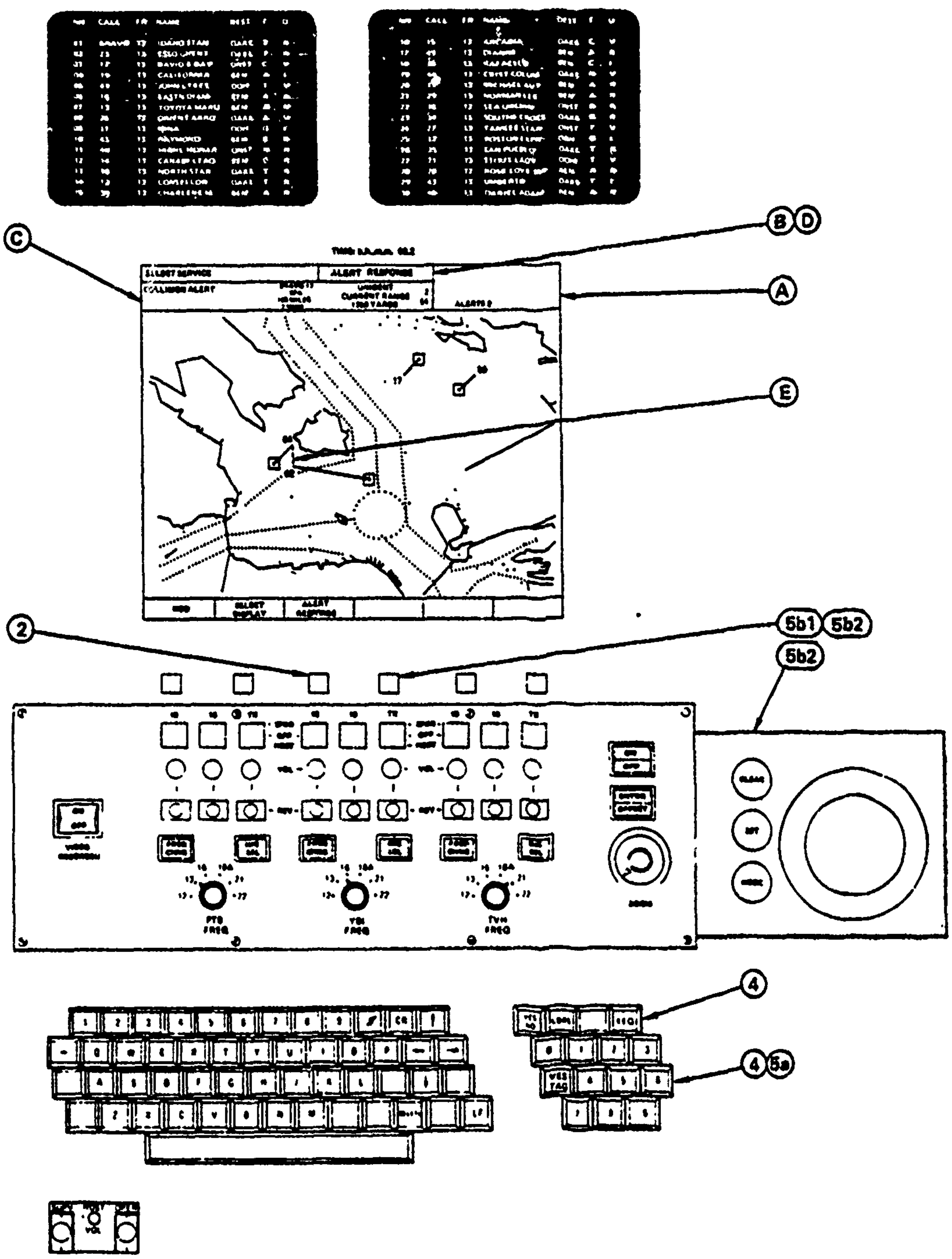

FIGURE II-2. VTS DISPLAY CONSOLE

On the Working Display, the operator may display either the map--as in Figure II-2--or the contents of the satellite displays, which provide information on the name, course, and destination of the vessels in the bay. The scale of the map may be changed and its center displaced to allow the operator to examine a particular area in greater detail. Associated with the map are windows that provide the operator with supplementary information on the status of vessel traffic in the bay. In the figure, for example, the system has generated a collision alert for two vessels whose current range is 2,000 yards and closing.

The method used to generate the map for the Working Display is one of the most interesting features of VTS. The system employs a synthetic display. Rather than displaying the video returns from the radars directly--e.g., in the form of a PPI display--only the processed, firm tracks are shown on the map. These tracks are stored in the TAD computer and are read out periodically to generate the display. Thus, neither clutter, undetected vessels, nor new or tentative tracks appear on the map

In addition to the firm tracks, traffic lanes--whose boundaries are indicated by dotted lines--vessels, buoys, and other identifiers are also displayed on the map. The complete set is listed in Table II-1. Special symbols are provided for buoys, buoys that are adrift, and lost contacts. Identified vessels--those with which radar contact has been established and which have been correlated with a firm track--and unidentified vessels are distinguished. The identified vessels have their name, course, and destination displayed on the satellite displays. The leader line, which can also be seen in Figure II-2, is used to display the heading and future position of a vessel. The remaining symbols on the display--cursor, hook, and set--are used by the operator to request specific operations. These will be described later.

TABLE II-1

DISPLAY SYMBOLS

SYMBOL	NAME	SYMBOL	NAME
AUTOMATIC SYMBOLS (ALL DISPLAYS)			
••••••••	Lane Boundary	⊡	Identified Active Vessel
•	Buoy	⦿	Unidentified Active Vessel
	Drifted Buoy	⊡ 05	Vessel Number (or Tag)[a]
X	Out-of-Track Buoy	X 05	Lost Identified Contact
OPERATOR CONTROLLABLE SYMBOLS (WORKING DISPLAY)			
↑	Cursor	X	Set
○	Hook		Leader Line

[a]The operator can choose to display the number or not to display it.

C. AUTOMATIC SYSTEM FEATURES

Most of the automatic features of the VTS employ the Automatic Detection and Tracking (ADT) subsystem. As previously described, this subsystem permits vessels to be detected through the use of an adaptive threshold that is keyed to the average clutter return. The automatic features available to the operator at the main console which use the ADT subsystem may be classified into those that are available by operator request and those that are provided by automatic alerts. These include:

- By operator request
  - -- Speed and course data. For identified vehicles, the operator may display a vessel's name, position, heading, origin, destination, size, and ancillary identification data.
  - -- Future position. With the leader lines, linear course projections can be made for 1-, 2-, or 6-minute intervals.

-- Relative position. The relative position capability permits the operator to select a point--usually a vessel--using the track ball and then to select a second point--also usually a vessel--and to obtain the bearing and range between the two points. The values of the range and bearing are printed in a Working Display window and a vector between the two points is displayed on the map.

-- Closest point of approach (CPA). The CPA capability is similar to the relative position calculation except that the bearing range determination is made at the point of closest approach of two vessels or of a vessel and a fixed point. The time to CPA and the range at CPA are displayed in a window of the Working Display.

- By automatic alert

-- Potential collisions. A collision alert is generated if a vessel closes to within 1,000 feet of another vessel within the next 4 minutes. The warning is both audio and visual. The "collision alert" in the Working Display of Figure II-1 corresponds to the visual portion of the warning. Upon notification of the alert, the operator may request the CPA for the two vessels. The position and orientation of the vessels are then displayed on the map. If the situation persists, the developing situation may be recorded for future reference.

-- Drifting buoys. A buoy that drifts off station has the normal dot--see Table II-1--replaced by a dot with a diamond on top. No audio warning is supplied.

-- Loss of track. When track is lost on an identified vessel, a blinking "X" appears at the last known location of the vessel with a leader line showing the speed and course at the time of loss. A blinking "R" also appears on the Vessel Data Display opposite the name of the vessel. Loss of track on a drifting buoy also causes an "X" to appear at the last known contact, but the symbol does not blink nor is a leader line attached.

Other automatic features are included in the system. Of most interest to the ODAP is the treatment of multiple alerts. The procedure used in the system for handling them is to first assign a priority value to each alert. For example, if alerts are generated for two potential collisions, the one with the shorter time to collision is assigned the highest priority. The alert with the highest priority is then displayed in one of the windows of the Working Display called the Alert Message Section. If the alert is a potential collision, the window contains the designators of the two vessels involved and the time to collision. Also displayed in the window is a second message giving the total number of alerts in the system. When the first alert is processed--for example, by requesting the positions of the vessels at CPA--the alert with the second highest priority automatically appears in the window. The procedure is then repeated for additional alerts.

D. DISCUSSION

1. System Development: Approach

The approach is probably the most important element in the development of a system. The key to the approach is the clear, unambiguous, and mutually agreed upon definition of what the system is supposed to do, i.e., the functional requirements for the system. The developers of VTS strongly support this view and, in fact, recommend a four step approach to system development:

- The definition of the functional requirements for the system. This step requires the determination of precisely what the system is required to do. It provides the developer with a well-determined set of design objectives and minimizes the likelihood of the need for later revisions in the system due to a lack of common understanding of the requirements of the system.
- The preparation of the conceptual design. This is the qualitative design of the system. For example, in VTS during the conceptual design phase, it was decided to use bright interactive displays.
- The determination of the hardware and software specifications. In this step, for example, the specifications necessary to define the ADT and TAD systems are established.
- The selection or design of the necessary hardware and software. This includes the development of the mathematical algorithms necessary for the system. It is the area of primary focus in the ODAP.

The adoption of this approach alleviates many of the common problems in system development that stem from a lack of understanding of the functional requirements for the system or from a failure to systematically translate the requirements into the detailed characteristics of the system.

2. System Development: Communication

The need for close and protracted interaction between the developers of a system and the eventual users was strongly emphasized by the developers of VTS.[1] In developing VTS, they literally spent weeks in San Francisco working with the operators to develop both the functional requirements and the conceptual design of the system. They described this phase as the most difficult and important part of the development. Detailed discussions with the operators indicated that they did not initially have a clear understanding of what was needed in the new system, nor were they able to evaluate effectively a particular design before they saw it in operation. Thus, the developers had to work very closely with the operators to develop their own understanding of the existing system and the requirements for the new system. Throughout the subsequent development of the system, the developers maintained very close contact with the operators to help keep the program on target and to give the operators the opportunity to keep abreast of the program. The system developers said that without this interaction the system would probably not have been successful.

One persistent problem that arose repeatedly during the discussions between the system developers and the operators was their lack of common language. In many instances, the developers and the operators simply did not mean the same thing by the same words. And the situation was further complicated in instances where a subject was not thoroughly discussed because "everyone knows what needs to be done there." It became apparent that where there is a difference in background between developers and users--as there nearly always is--all aspects of a problem must be discussed in the most concrete and detailed way in order to insure a common understanding. The designers of VTS recognized this and their persistent and protracted discussions with the operating personnel appear to have contributed substantially to the successful development of the VTS system.

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[1]The developers of VTS also emphasized that the Coast Guard was very much aware of the need for a close working relationship between the two groups and cooperated fully with them.

3. System Development: Information Filtering

A major problem that arises in almost all automated decision systems is the generation of more data than the decisionmaker can handle effectively. In these systems some method must be developed to reduce the data load to an amount and form with which the operator can effectively work. In VTS this is accomplished by means of the synthetic display.

The synthetic display permits the operator to view only the firm tracks. Clutter and other imagery that appear on a PPI is suppressed on the synthetic display. The operator, therefore, has to deal only with data that is relevant to his decisionmaking process.

Although this procedure considerably simplified the analysis of data, problems with the procedure arose as a consequence of: (1) an operator concern that buried in the raw data is another vessel for which a firm track had not yet been established and which, therefore, does not appear on the synthetic display, and (2) a psychological need for the operator to view all data produced by the system. Experimental verification that the ADT subsystem detected vessels far more effectively than the unaided human observer did not alleviate the problem.

This situation, in which the raw data is not available to the operator leads to less than full satisfaction with a system, is common to many of the systems we have examined. It strongly suggests that a useful principle in system design is to preserve and provide a capability within a system that permits the operator to observe the raw data if he so desires. For VTS, the situation was easily corrected by placing two PPI displays to each side of the Working Display. An operator then had immediate access to the raw data.

In sum, a major problem in developing computer-aided decision systems and especially in developing any form of fully automated decision system is in condensing, filtering, evaluating, and presenting the large quantities of data that are generated. The problem is particularly acute in a hostile environment in which it is the unusual items of data or an unanticipated pattern in the data that is important. Researchers have, in general, tended to shy away from the problem because of the difficulty of the problem, because other relatively more easily solved problems are also pressing, and because solutions tend to be tailored to specific applications. In our judgment, more research in this area is certainly warranted and the payoff resulting from the research is likely to be considerable.

4. System Acceptability: Appearance

The physical appearance of a system often plays a critical, if not decisive, role in whether a system is accepted by the users. Nevertheless, we have found that, this seemingly self-evident principle is repeatedly violated by system developers. The tendency to overlook the importance of physical appearance is particularly pronounced among those with an academic orientation, who have a tendency to be preoccupied with the development of mathematical algorithms, with procedures for retrieving information, and with clever ways for performing their particular calculations. They tend to forget the potential users of the system, whose acceptance is critical to its success, and who rarely understand or care about the detailed structure of the system itself.

The developers of VTS fully appreciated the importance of the appearance of a system and, in fact, expended considerable resources in modifying their system to make it more attractive. As originally designed, the VTS system used storage tube displays. With this type of display an image--such as the map appearing on the Working Display--can be written on a storage surface within the display tube. Therefore, neither the map data nor the associated software required for repeatedly "refreshing" the display, needed to be stored in the computer.

After work with the system was partially completed, the developers found that the display "did not look very good" and tended to go out of alignment, thereby requiring an unusual amount of maintenance. A decision was then made to use computer-refreshed displays, in which the map is continually refreshed in a manner similar to that used in conventional television receivers. This change required extensive reprogramming of the software for the system and dedication of valuable storage to preserve the map data, but the developers of VTS felt appearance to be of such importance that the change was justified.

5. System Acceptability: Ease of Learning and Operation

In the development of many new systems, the training of operators is discussed seriously only when the design of the system is nearly completed. Frequently, at this stage extensive training programs for the operators are proposed and, occasionally, the point is reached where a Ph.D., skilled in the particular discipline, is recommended to head the user team. All sight is lost of the general principle that successful systems tend to be easy to learn and easy to operate. This principle can often be easily met, or at least the burden placed on the operators greatly alleviated, simply by giving greater attention to the requirements placed on the operators during the initial design phase of the system.

The development of systems that are easy to learn and operate can benefit a developer in many ways. Many visitors to APL observed the displays and were favorably impressed by them. As a consequence, APL had the opportunity to consider the use of the displays in other programs.

In developing systems for other programs and other customers, an important point that should be carefully considered in planning a new system is that the "personality" of the customer for whom work is done can substantially influence how the work must be performed. The Coast Guard, for example, was a new customer to R&D. As a consequence, they were not locked into standardized procedures and technologies and were especially open to new and innovative ideas. APL was, thus, able to exercise great freedom in both the design and selection of hardware for the system. By contrast, the Navy is very experienced in R&D. Consequently, a designer developing a new system for the Navy would find it necessary to accommodate what was being done by others, to obtain multiple approvals for each new feature of the system, and to use approved equipment--e.g., the UYK computer. A designer would thus need to develop a system for the Navy within a much tighter set of constraints than APL found necessary for the Coast Guard.

6. Acceptance of Automation: Key Events

There is often a strong reluctance among users to accept a new computer-aided decision system. To overcome this reluctance and to check out the system, there is frequently a period in which the old manual and the new automated system are used concurrently. The eventual acceptance or rejection of the automated system then frequently depends on the outcome of certain key events in which one or the other of the systems fail. A simple example of this type, which had a favorable outcome for the automatic system, occurred in VTS. An operator working in the automatic mode concluded a particular vessel had run aground. (The velocity readout was zero.) The operator of the manual system strongly disagreed. Shortly thereafter, the captain of the vessel radioed and confirmed he had indeed run aground. Henceforth, the automatic mode was looked upon with considerably more favor.

Just as such favorable events contribute to the acceptance of a system, unfavorable events can contribute to its rejection--often much more dramatically. One case, involving only a very limited amount of automation, occurred in introducing digital depth gauges to submarines. The digital gauge was intended to supplement the mechanical analog gauge that had been in use for many years. It was introduced on a display along with two analog gauges that provided the manual backup. As it turned out, the digital gauge on one submarine failed. For some reason the operators did not observe the backup gauge and the ship was endangered before the operators became aware of the situation and were able to take corrective action.

As a consequence, a veritable outcry was heard within the Navy that culminated in an order to remove the gauges from the submarines. This occurred notwithstanding the fact that analog gauges also fail and the cause of the failure of the digital gauge was readily correctable.

A second example is provided by the Navy's Conologue system. Conologue was designed to aid an inexperienced helmsman. In order to remain on a prescribed course and at prescribed depth, the helmsman need only follow a highway depicted on a CRT. If the submarine drifts to the right of its prescribed course, the highway moves to the left on the CRT, and the helmsman might adjust his course to the left, to move the highway back to the center of the display. If the submarine drifts above its prescribed depth, the highway moves to the bottom of the display and the helmsman must then adjust his heading downward to move the highway back to the center of the display.

In tests at sea the system proved to be very useful, especially in a rough sea where it is difficult to maintain a prescribed depth. Based on its successful performance in these tests, operational implementation of the Conologue system was approved.

In operation the system ran into extensive problems. Maintenance time was excessive. Documentation of the technical characteristics of the system was so poor and maintenance training so incomplete that correction of one problem frequently created another. Dissatisfaction with the system soon grew rampant and eventually resulted in an order to remove Conologue from the fleet.

In both of these examples there were no fundamental problems with the decision aid. In the case of the digital depth gauge the problem was probably unavoidable; whereas, with Conologue, greater attention to system support function might have avoided the problems that were encountered. The essential point, however, is that in a computer-aided decision system where there is inevitably a reluctance by users to accept the system, the greatest care must be exerted to avoid system failure if the system is to be accepted. Such commonly heard arguments as: "We are only testing out a new principle; we do not have to worry about operational details," and "Operational problems are someone else's headache, our interest is in the mathematical development" are wholly inconsistent with the attitude and approach that has been adopted in the development of successful systems.

7. System Acceptability: Documentation

The contribution of documentation toward gaining the acceptance of a system has been noted in the discussion of the Navy's Conologue system. The developers of VTS paid considerable attention to the preparation of useful and easily assimilable documentation. Figure II-2, which we discussed earlier in the chapter, was taken from a document on console operation that provides a reference source for each of the activities (service procedures) that the operator must perform. The alphanumeric designators appearing in the figure are identified in Table II-2, which followed Figure II-2 in the original document. Note that each operational step is clearly defined, including a statement of its purpose and the results of completing the step. References, such as "hook, "XEQ," and "Real Time Data Service," are carefully defined earlier in the document.

The clarity of this particular example is representative of the quality of the entire set of documents and reflects the care and attention that was given to its preparation. We feel that it contributed significantly to the acceptance of the system.

E. SUMMARY

We end the chapter with a quote from Mr. Andreas C. Schultheis, Program Manager of the VTS system development at APL:

> I believe that the C^3 system design is predicated on a tradeoff between available state-of-the-art technology and philosophy, all based on good common sense and understanding of the mission's operational requirements. In my work I have not found any major design formulas and I really do not think they exist. I found you have to learn to put yourself in the operator's seat and imagine how you would want the operation to run--what displays, data, and information are needed to perform the mission. To build a successful system, it then takes a unique blend of technical knowledge of what can be done, a very good appreciation and understanding of operational requirements, and detailed knowledge of mission requirements.

TABLE II-2

OPERATOR SERVICE PROCEDURE 2-31 COLLISION WARNING ALERT RESPONSE

STEP NO.	OPERATOR PROCEDURE	PURPOSE	RESULTS		REMARKS
			NORMAL	ERROR	
1	Observe Alert condition in Alert message sector of Working Display Ⓐ.	Initial notification of potential collision condition.			Collision Alert message may read similar to the example shown. COLLISION ALERT VESSELS 04 XX 2 MINS ALERTS 3
2	Press Alert Response Function Button.	To obtain CPA information on subject collision condition.	Alert message is removed from Working Display Ⓐ and next priority alert message (if any) takes its place. Alert Response service appears on Working Display Ⓑ. CPA information appears in Information to Operator Sector Ⓒ. CPA vector picture appears on map Ⓔ.		
3	Determine seriousness of Alert condition then perform one of the following applicable steps. a. Non Hazardous (refer to step 4). b. Hazardous (refer to step 5).				Vessels are aware of condition and are taking corrective maneuvering action. Condition continues to deteriorate and vessels are not taking corrective maneuvering action.
4	NON HAZARDOUS Call for another service by typing appropriate code on control keyboard and then pressing XEQ.	To return to regular tasks.	Desired service is on Working Display.		Refer to Operator Service Procedure 2-1 for details on how to call for service.
5	HAZARDOUS For a hazardous condition perform the following: a. Call for Real Time Data Dump service by typing code 33 on the Control Keyboard. b. Using the Trackball assembly perform the following: 1. Hook the first contact and then press ENTER Function Button. 2. Hook the second contact and then press ENTER Function Button c. Go to CPA service and monitor the tracks of the two vessels.	To prepare for data printout on vessels involved in collision condition. To start printout on vessels involved in collision condition.	Real Time Data Dump service is presented on Working Display Ⓓ. Printout starts.		Refer to Operator Service Procedure 2-27 for details on Real Time Data Dump Service. Refer to Operator Service Procedure 2-7 for details on how to hook a contact. This will provide a record of the tracks of the two vessels involved.

F. SOURCES

Mr. Andreas C. Schultheis was Program Manager for the Vessel Traffic System (VTS) at the Applied Physics Laboratory of the Johns Hopkins University. Documentation of the Vessel Traffic System, entitled San Francisco Vessel Traffic System Operations and Maintenance Manual, Vols. I, II, III, December 1973, is available from the National Technical Information Service, Springfield, Virginia 22151.

III. THE STANDOFF TARGET ACQUISITION SYSTEM (SOTAS)

The Standoff Target Acquisition System (SOTAS), under development by the U.S. Army Electronics Command, is designed to assist a military commander in making decisions concerning the deployment and utilization of his forces. SOTAS gathers and processes useful and timely information on target movement and location in the region beyond the ground line-of-sight, and then transmits this information to the division.

SOTAS differs from other computerized decision aids described in this report in that it is an independently developed system that must be integrated into an existing command and control system. As such, it provides an excellent case study for the ODAP. Most operational decision aids now actively in use consist merely of the automation of existing well-structured procedures and, thus, do not face the integration problem.

A. SYSTEM DESCRIPTION

U.S. military forces are not currently equipped with effective means for detection, location and tracking of enemy ground targets beyond ground line-of-sight. SOTAS provides this capability through the use of an airborne radar that relays imagery in real-time to ground display facilities, which process the data and relay it to a command center.

The proposed configuration of the system is shown in Figure III-1. It consists of a helicopter, equipped with an MTI radar; a master ground station (located in the display trailer) equipped with CRT displays, a computer and magnetic tape memories; a ground radar tracker; and one or more remote terminals having similar but reduced capabilities to those of the master ground station. In operation, the radar returns are processed to detect

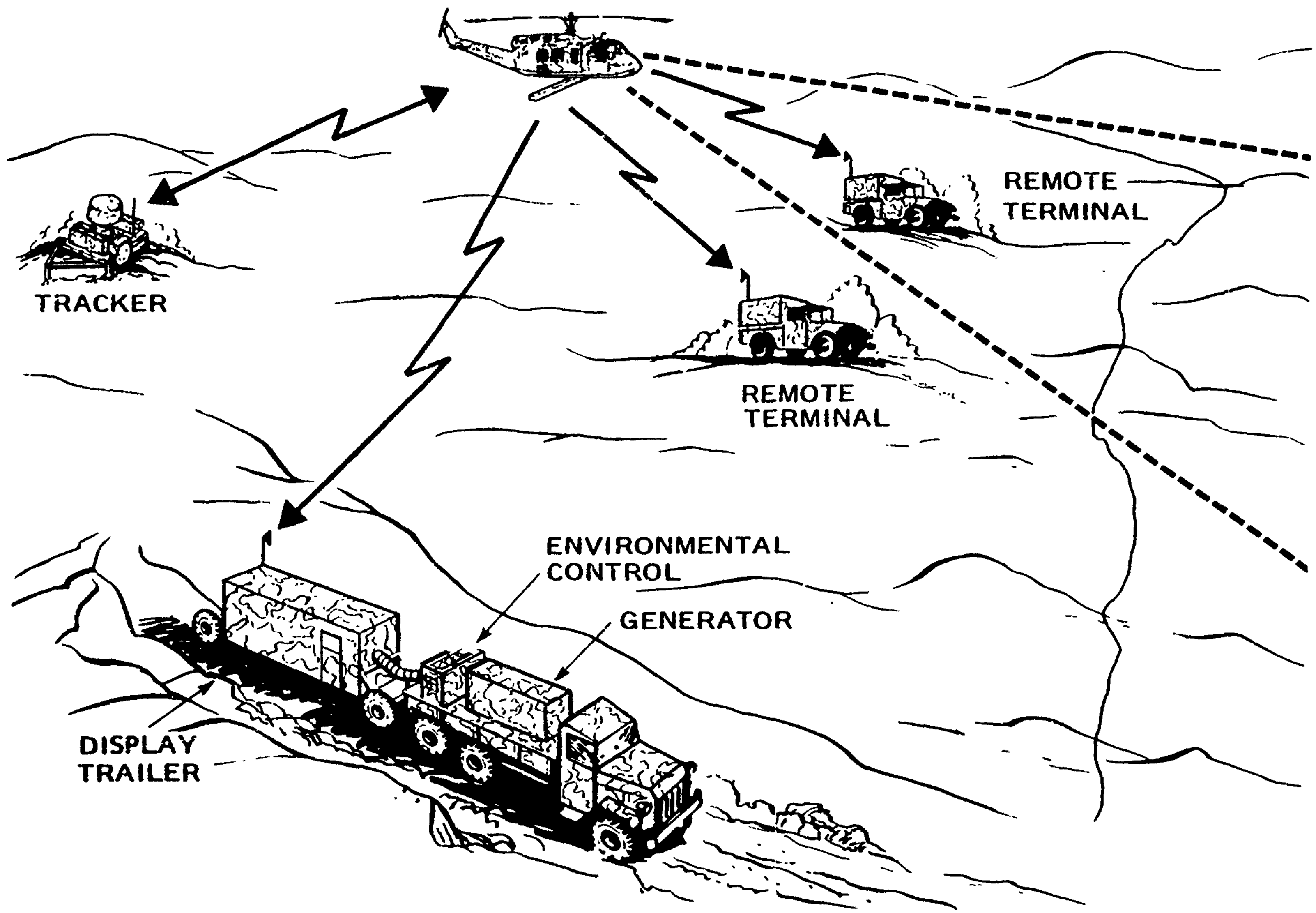

FIGURE III-1. THE STANDOFF TARGET ACQUISITION SYSTEM (SOTAS) moving targets, converted to digital form, and transmitted to the ground station for display and recording. The ground computer and CRTs provide either real-time display or time-compressed playback of imagery. The radar tracker tracks the helicopter, so that target coordinates measured in the helicopter system can be accurately expressed in a ground-based system. The remote terminals permit direct access to the data from the helicopter by elements having a need for near real-time information.

B. SYSTEM INTEGRATION

The Vessel Traffic System (VTS) is a complete, stand-alone system that totally replaced the existing command and control system for monitoring and advising vessel traffic in San Francisco Bay. SOTAS, on the other hand, supplements the existing Army command and control system by providing data on targets lying beyond the line-of-sight of the ground forces. SOTAS data is combined with data from other sources to provide the information needed by the tactical commanders in their decisionmaking roles. Therefore, for SOTAS, consideration must be given to a system integration which is not faced by VTS.

The nature of the integration problems as they relate to automated decision aids becomes apparent when the flow of information through the SOTAS system and into the command and control system is examined. This flow begins with the collection of large quantities of raw data by the helicopter and transmission of this data to the ground station. At the ground station an operator examines the data on a conventional CRT display and identifies those activities that appear to warrant further evaluation. In the course of executing this procedure, the operator must address such objective questions as "Which data are clutter?" and "Which data represent the movement of a tank column down a road?" and such more judgmental questions as, "Which data, when perceived as a pattern, indicate the presence of unanticipated activity in the battlefield?"

After the operator has processed the data in the master ground station, it is forwarded to an officer-in-charge, who, after reviewing and further interpreting the data prepares a message for transmission to the Division Tactical Operations Center (DTOC), which is the connecting link between SOTAS and the command and control system. The form in which information would typically be conveyed is illustrated by the following message:

> An enemy heliborne operation has just begun at 0182 proceeding from Heidelberg in a North-Easterly direction at 45 knots. There appears to be 10 vehicles in the formation.

Upon reception of the message at the DTOC, it is integrated with data from other sources and then used in planning, in making real-time force and combat unit assignments, and in other decisionmaking activities.

The examination of information flow in SOTAS and between SOTAS and the DTOC illustrates a number of important points. The first is the degree to which the command and control system determines the requirements for and the configuration of the SOTAS system, as well as the requirements for individual decision aids. Without the explicit recognition of and accounting for this relationship, it would be extremely difficult to develop an effective and, indeed, even a workable system.

The second point concerns the complexity of the interface between SOTAS and the command and control system. As a consequence of this complexity, a validation of the effectiveness of the system requires a demonstration that the system could be interfaced with existing or proposed command and control systems. This is a point especially relevant to the ODAP, which must not only demonstrate that useful aids can be developed using the methodologies under study, but that they can be incorporated into the command and control systems. The work in the ODAP for the Interim Tactical Flag Command Center (ITFCC) represents a step in this direction.

The final point concerns the implications of the information processing requirements for automation. The activities which led to the preparation of the message on the heliborne operations involved considerable interpretation, evaluation and judgment--activities which are generally felt to be better performed by human beings than by computers. Although the computer could be helpful in many of the intermediate calculations, the automation of the full process appears to be beyond the present data capabilities of computers and software designers.[1]

C. COMMAND AND CONTROL STRUCTURE

In the preceding section, the discussion stressed the structure of SOTAS and its interface with the command and control system. In the discussion, the command and control system was represented only through the Division Tactical Operations Center (DTOC), which integrated the data from SOTAS with data from other sources for use in planning, in making real-time artillery assignments and in other decisionmaking activities. In this section, we will describe the interface of SOTAS and command and control system in greater detail.

1. Organizational Structure

A major consideration in developing an operational system is the integration of the system into the existing organizational structure. Traditional organizational structures were not developed for modern computerized

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[1] In general, the investigation uncovered very little interest in fully automated systems. Commanders, in particular, expressed an extreme reluctance to permit computers to make decisions that affect the survival of their own forces. In such situations, they felt it was imperative to have a man-in-the-loop. The notable exceptions where full automation has been implemented have occurred in situations where a man cannot react quickly enough to make and implement the necessary decisions. For example, reactors on nuclear submarines are automatically shut down in the event of a malfunction; naval steam boilers have their water levels regulated by a simple control device, because man is unable to react quickly enough to regulate them in a combat environment. In the latter case, however, the commander generally still assigns a man to watch the water level for failure of the device endangers the safety of the ship, and the commander does not have sufficient confidence in the device to leave it unattended.

warfare and may, therefore, not be ideally suited to it. As a consequence, a decision aiding system may look more attractive in a benign environment than in an operational environment.

SOTAS provides a good example of a system that must be examined in an operational environment. SOTAS was designed to perform surveillance and target acquisition functions. In the former role, SOTAS monitors enemy activity in the region lying beyond ground line-of-sight. In the latter role, SOTAS locates individual targets or clusters of targets and transmits their location to the elements capable of responding with maneuver forces or weaponry.

Within the present Army structure, the intelligence branch is responsible for surveillance; the artillery branch, for target acquisition. Hence, the roles of SOTAS cross current organizational lines and SOTAS must be integrated into both organizational elements. There is then the strong possibility that existing procedures and practices for conveying information between the organizational elements may offset some of the advantages gained from use of the computerized system. The time saved by using the system in gathering and conveying information to a commander, for example, may be of relatively little advantage due to significant procedural delays in conveying information between the structured elements.

The implications of organizational structure for the ODAP is not currently a major concern, as the ODAP is limiting its attention to assisting the task force commander. Any extension of scope for the project, however, could make organizational structure a significant area of concern. The ODAP is already studying ways to reorganize the task force commander's staff in order to more effectively use the decision aids now under development.

2. System Role

The determination of a precise role for a system such as SOTAS that is to be integrated into an existing command and control structure is a step that must be taken in system development. SOTAS provides data from beyond ground line-of-sight. But for whom? And in what form? In the SOTAS program, these were questions that were addressed and resolved during the advanced development of the program. However, the answers to such questions are often not only difficult but frequently changed during the development of a system as the requirements are revised. Although conceptually they may appear to represent only minor modifications to the system, operationally they may represent very significant changes.

The problem of role determination will likely soon confront the ODAP. A number of the aids under development have reasonably clear applications and the ODAP should give serious attention to how they will be integrated into the existing command and control system. Problems in this area are almost certain to arise and advanced attention to them can almost assuredly simplify the integration of the aids into the existing command and control system.

3. Measures of Effectiveness

The development of measures to assess the effectiveness of a system is a problem common to nearly all decision aiding systems. The development of such measures has obvious benefits to the system designers; they can use the measures as criteria for developing, evaluating, and improving the system. They also have the additional benefit that a commander is much more likely to respond favorably to a system if it can be demonstrated to him that he can make decisions more effectively with the system than without it.

The development of measures of effectiveness is a difficult undertaking for the system designers, because they must generally evaluate a system apart from the command and control system in which it will operate. Simple intuitive measures of effectiveness when applied to an isolated system have often proved to be unsatisfactory.

In systems such as SOTAS, one measure of effectiveness might be the amount of information--i.e., the throughput--made available as a result of using the system. One might like to say that the more information the system made available, the better the performance of the system. SOTAS demonstrated in at least one instance that this was not the case. In that instance, the transmission of data on all detected moving targets (without intermediate editing to evaluate the military importance) overloaded the receiving tactical element and the performance of the system decreased.

Another potential effectiveness measure is the timeliness of information. Timeliness would be of most value against perishable targets. An MOE might show that a significant reduction in processing time by the system would significantly increase the overall effectiveness of the combat forces against perishable targets. However, this is also not necessarily true. For example, as indicated earlier, the time required to relay the information from SOTAS to the controller responsible for assigning weapons to targets, plus the time required for the weapons to reach a target could exceed the time available for attacking it.

Tests of the SOTAS were used to investigate the impact of additional time delays introduced by the normal processing channels. In some instances, these time delays were found to be excessive. As a consequence, the remote terminals, shown in Figure III-1, were introduced into the system. These provide the forward forces with the immediate information they require to respond quickly and effectively to enemy action.

D. SPECIAL PROBLEMS

A number of special issues are addressed in this section that have not been covered in detail in other parts of the report.

1. Other System Competition

The capabilities of other systems that might perform roles similar to the system under development must be assessed. For example, the primary role of SOTAS is to gather data on targets lying beyond the ground line-of-sight. By being positioned behind the FEBA, it is relatively invulnerable to ground fire and because of the tracker, it can probably pinpoint target locations more accurately than other systems. Nevertheless, other systems can perform portions of the overall SOTAS role, and must be taken into account when evaluating the overall worth of the system.

At this time, the issue of other system competition is of particular relevance to the ODAP in the selection of potential aids for development. With a potentially broad spectrum of aids available, an awareness of what related work is being performed elsewhere--even if performed at a much lower level of sophistication than in the ODAP--would be of considerable value in selecting aids for development in the program.[1]

2. Field Testing

The developers of SOTAS have stressed the advantage of giving the military commanders, the eventual users of the system, the opportunity to appraise the system at an early stage of its development. By providing this exposure to the system, they felt they could develop both a better system and engender the support of the users for the system. For SOTAS, this approach has been highly successful.

E. SUMMARY

This chapter concentrated primarily on the problem of interfacing a decision system or set of decision aids to an existing command and control structure. The development of this interface represents an area which presents many problems of substantial difficulty, which hinders the development of automated systems, and which have been largely neglected by theoretical researchers. In our judgment, it also represents an area which has not been adequately addressed by the ODAP. And since it impacts significantly on the feasibility of successfully implementing the ODAP decision aid methodologies, we feel it represents an area in which the ODAP could profitably address greater attention.

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[1]Some of the work is described in this report. The bibliography contains references to additional work of potential interest to the program.

IV. TRIDENT/SSN COMMAND AND CONTROL

In the chapters on VTS and SOTAS, we emphasized decision aiding systems; decision aids were discussed as they related to those systems. In this chapter the emphasis will be on the decision aids themselves, specifically on those aids under development for the defensive command and control system of the TRIDENT submarine. Although strictly speaking these are aids for a ship commander rather than a task force commander, they provide an excellent example of the current state-of-the-art in operational decision aids. They come as close as any operational aids we have seen to those under development in the ODAP.

In the discussion to follow, we will explicitly address such questions as:

- At what level of mathematical sophistication are the aids?
- What are the characteristics of the situations or activities in which the decision aids are used that make them attractive for using aids?
- To what extent could the aids have been developed independently of the specific systems and then integrated into them?

In addition to the development of specific decision aids, attention has been given in the ODAP to changes in the organizational structure of the commander's staff to accommodate the decision aids. A related problem area that affects organizational structure is the physical configuration of the decision aids within a command center--the physical location of the specific aids, the number of displays required, the aids that can share displays, and so forth. We will outline the approach taken in the SIAC/SSN (Submarine Integrated Attack Center) program to illustrate the procedures that are used in developing such a configuration. What will become clear from the discussion is the need for considering the operational situation in developing efficient configurations.

A. OVERVIEW OF DECISION AIDS

A modular approach was adopted in developing the decision aids for the defensive command and control system in TRIDENT. Control consoles and display equipment are located in the Command and Control Center (CCC). A separate module is under development for each of the activities of the ship requiring command decision--search, track, torpedo evasion, and so forth. The modules are developed independently but with predetermined system interfaces--input and output data sets and formats--so that they can be easily integrated into the system. Modifications to a specific module can then be made without reference to other modules in the system and specific modules can be replaced by completely new ones. Among the command modules in TRIDENT are the following:

1. The Operations Summary Module

This module serves as the principal means of depicting for the commanding officer/officer-of-the-deck (navigator) the best available information regarding the general tactical situation external to the submarine. It functions as an all-source data collection and display mode for information pertinent to the operations of the ship.

2. The Search Management Module

This module provides the capability to plan search procedures that maximize the probability of detection of surface ships or submarines reported or expected to be within the TRIDENT's operating area. It permits the operator to preview quickly the implications of changes in own ship's depth, speed, and sonar configuration or sensor performance. It thus serves as an aid to assist the operator (commander) in devising near optimal search patterns. (It does not devise the pattern for him.)

3. The Avoidance Management Module

This module provides a capability to present displays depicting the likelihood of counterdetection of own ship. It assists the operator in evaluating depth and speed combinations for his own ship that minimize the probability of being detected by a specified target type. Thus, it shares with the Search Management Module the property of serving as an aid to assist the operator in planning rather than in automatically generating courses that minimize the likelihood of counterdetection.

4. The Torpedo Evasion Module

This module provides information displays for threat assessment and countermeasures (static) employment in the event a hostile weapon (e.g., a torpedo) is detected in the water. An automatic alert is generated immediately on detection. Geographic and depth separation displays are presented to assist (once again) the operator in formulating evasive tactics.

5. Defensive Tactics Module

This module provides the capability for assessing the tactical situation with respect to a selected high threat contact and for determining presets, i.e., trajectories, for the MOSS programmable countermeasure. MOSS is a deceptive countermeasure that simulates the signature of the TRIDENT.

6. The Environmental and Data Entry Module

This module provides for entry and initial processing/filtering of the environmental and own ship background noise data for use by the other modules.

A principal characteristic of the structure of each of these modules is that they assist the operator (commander) in his decisionmaking process; they do not make decisions for him. Perhaps the most likely candidate for full automation is the Torpedo Evasion Module. Here the time available for making and implementing a decision may be so short that it eventually may become necessary to develop a fully automated capability.

B. EXEMPLARY DECISION AIDS

We now consider three specific decision aids which are indicative of the levels of sophistication exhibited by current or near-term decision aids and which manifest many of the characteristics and problems associated with such aids. At least one of the aids--the aid for exploring the consequences of adopting specific tactics for the MOSS countermeasure--approaches the level of sophistication of the outcome calculators under development in the ODAP.

The first aid, which is in the Search Management Module, assists the operator in planning and conducting a search. It provides a graphical display of the likelihood that a target whose characteristics are specified by the operator will be detected by the ship's sensors. The computation of the likelihood takes into account an operator specified speed, course, and depth for both the TRIDENT and the operator specified target, and the existing environmental conditions. The likelihoods may be displayed in either the horizontal or vertical plane. The horizontal display is shown in Figure IV-1.

In the figure the TRIDENT is located at the center of the dodecagon. The numbers at the vertices of the dodecagon denote the bearing of the vertices with respect to the bow of the TRIDENT. These are expressed in degrees and measured in a clockwise direction. The numbers along the x-axis represent range from the ship in standard units. The shaded regions represent areas in which a target with the operator specified characteristics would be detected with a probability greater than or equal to 50 percent. (The inner non-shaded area might, for example, represent shadow zones, i.e., an effect caused by bending of the ray paths due to spatial variations in the index of refraction.) Additional data are contained in the upper and lower windows which are blanked out in the figure. Included in the data are own ship and target depth and speed, maximum sonar range, and assumed sonar configurations.

The vertical display can also be used to show counterdetection probabilities assuming the best mode of propagation--as selected by operator--between own ship and target. The more complete all aspect return, counterdetection probabilities are calculated using decision aids in the Avoidance Management Module.

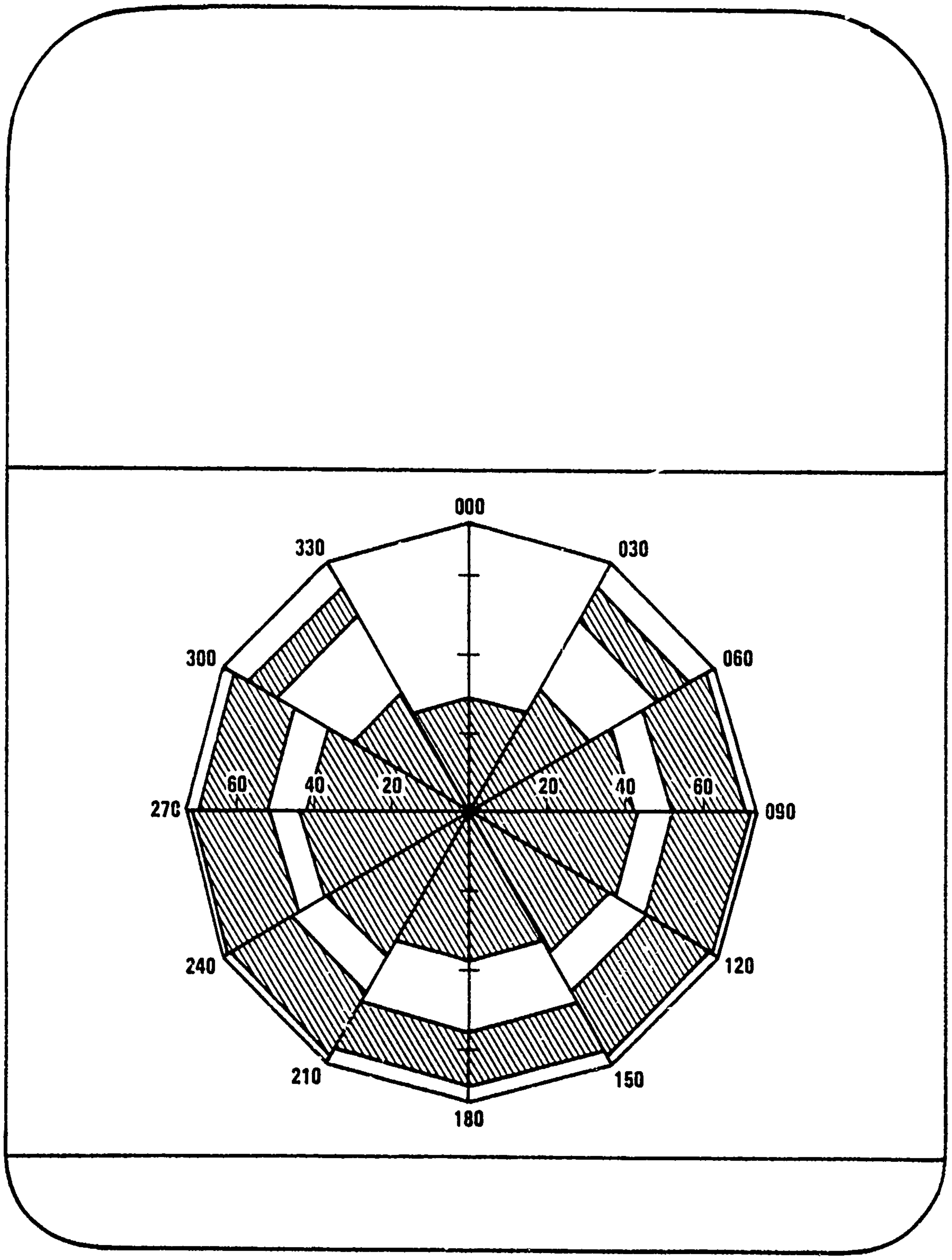

FIGURE IV-1. TYPICAL DISPLAY OF DETECTION PROBABILITIES IN HORIZONTAL PLAN FOR AN OPERATOR-SPECIFIED TARGET

The second decision aid we will describe assists the operator in responding to an imminent undersea attack. The aid is part of the Torpedo Evasion Module. Figure IV-2 illustrates the display for a three torpedo attack. The circle marked by a cross in the center of the display is own ship; the adjacent circle marked by an "E," a static countermeasure. The leader line eminating from own ship denotes its current heading. The series of points to the lower right of own ship denote its previous positions. The rays eminating from own ship and from its previous positions indicate the bearing of the torpedos at the corresponding times. (In this example only the bearings of the torpedos are known. If the ranges were also known, circles indicating their position would be shown on the display.) At the present time--as indicated by the three rays eminating from the own ship symbol--the bearing of all three torpedos is shown. For previous times, only the bearing of the first torpedo, which was selected by the operator for display, is shown. The time profile of the bearing of the first torpedo is also shown in the upper plot. Over the time interval covered by the display the true bearing has decreased from an angle of about 120 degrees to an angle of about 80 degrees.

To the left of the display is depicted the depth of own ship, the static countermeasure, and the three torpedos. Torpedos one and two are both at a depth of 200 standard units; torpedo three, at 100 standard units. Additional data shown on the display, but blanked out in the figure, include the status of the torpedos and the countermeasures. If the torpedos are active--i.e., emitting--the frequency, pulse width and pulse interval of the torpedo's sonar are shown.

Note that although the decision aid does not recommend specific evasive action to the operator, it does present him with all the information available on the threat in a simple, compact form. Using the information on the display, the operator can draw a number of immediate conclusions about the status of the threat. If own ship has been following a straight line course, the operator can conclude, for example, that if a torpedo remains at a constant bearing, it is on a collision course; or, if the bearing is rapidly changing, the torpedo is close to own ship.

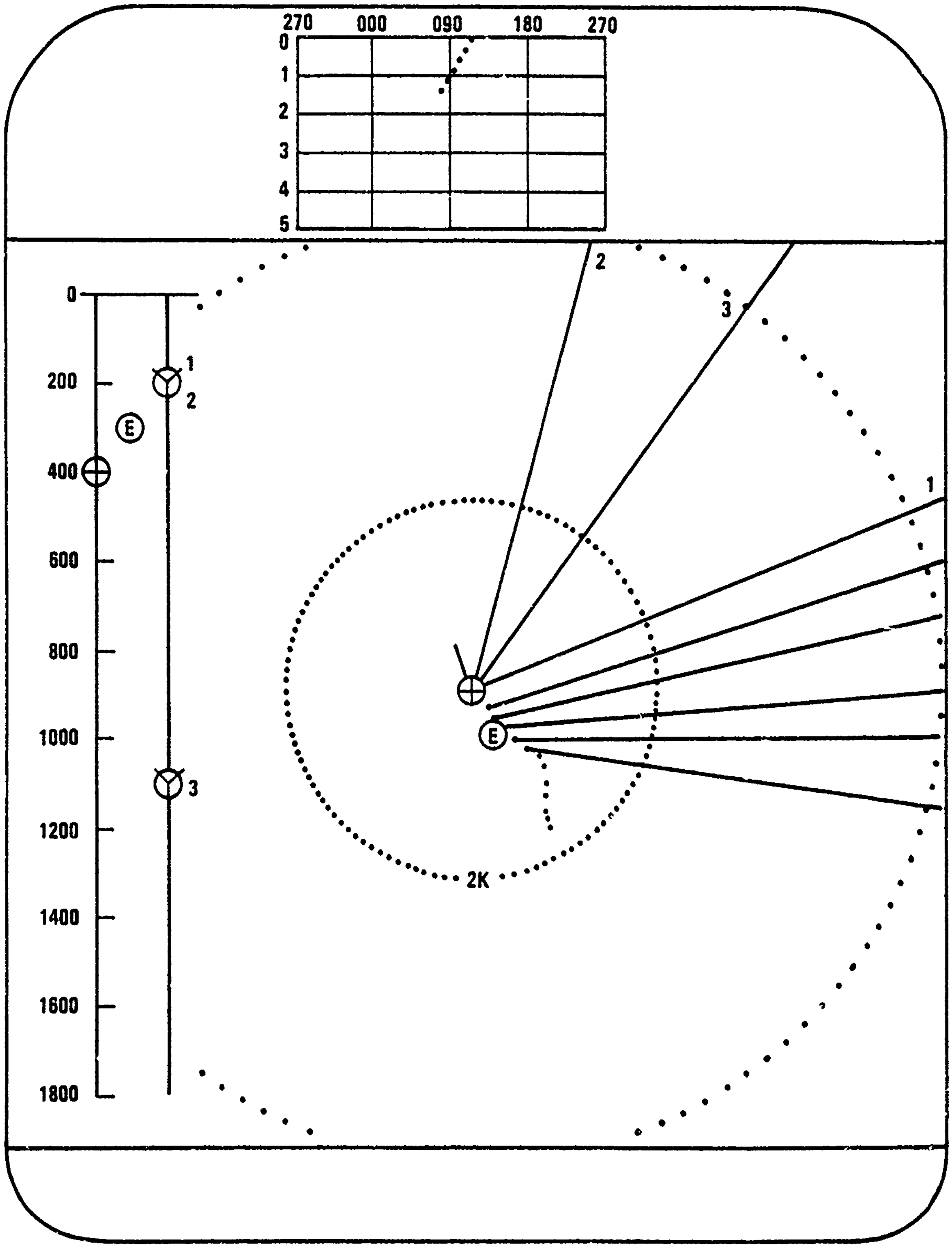

FIGURE IV-2. TYPICAL DISPLAY FOR OWN SHIP UNDER TORPEDO ATTACK

Figure IV-3 illustrates a decision aid that permits an operator to explore the consequences of adopting alternative tactics for mobile countermeasures. This decision aid most closely corresponds to the ODAP definition of an outcome generator. In the figure, the crossed circle denotes, as before, own ship; and the series of points eminating to the left, its previous positions. The leader line eminating from it denotes its projected future positions. The circle containing the dotted "V" denotes an enemy contact. The leader line eminating from it denotes its projected future position. The lines projecting from the leader line denote the bearing of own ship and enemy contact for projected future positions. The length of the lines is of significance. If the own ship were to close to within a "line" of the enemy contact, its probability of detection by the contact would exceed 50 percent. So to minimize the likelihood of detection, own ship should stay beyond the lines.

The line eminating to the right of own ship designates a possible tactic (course) for the MOSS countermeasure. The tactic selected--Tactic 6 in this example--is shown in the table at the top of the display. Additional tactics are also stored in the system and may be examined by the operator.

The purpose of the mobile countermeasure (MOSS) is to permit own ship to evade the hostile contact. To accomplish this objective, the operator selects a tactic which leads to a high probability of the enemy contact detecting and tracking the MOSS instead of own ship, thereby allowing own ship to move safely away. Tactic 6, displayed in the figure, moves MOSS well within the 50-percent probability of detection lines, with own ship remaining well beyond them. Tactic 6, thus, appears to be a desirable tactic for evading the enemy contact.

C. DISCUSSION OF AIDS: GENERAL CHARACTERISTICS

1. The situations or activities for which the aids have been developed may be characterized as well-structured, repetitive--in the sense they may arise many times--and non-novel--in the sense they represent situations

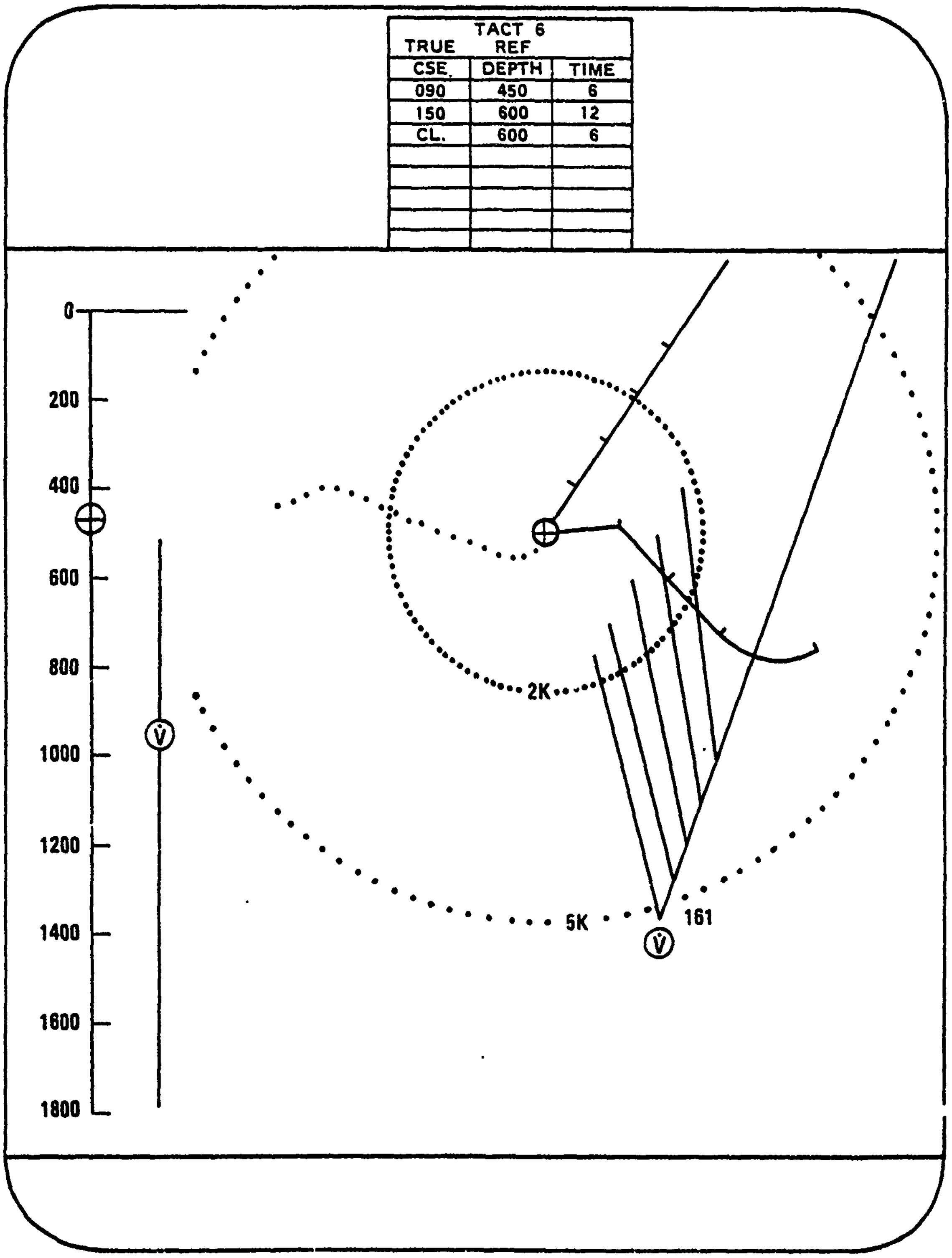

FIGURE IV-3. TYPICAL DISPLAY FOR EMPLOYMENT OF MOBILE COUNTERMEASURE that could be anticipated ahead of time. To a large extent the aids themselves also represent the automation of procedures that were formerly performed manually (on other shops) using tables, maps, and analog devices (e.g., slide rules). As a consequence, the developers of the aids do not encounter the type of system integration problem encountered by SOTAS. They simply replace the officer who would have performed the computations manually.

2. The level of mathematical sophistication of the decision aids developed for TRIDENT is significantly less than those under development for the ODAP. The detection probabilities and course projections required for the TRIDENT aids, for example, require the use of basic, well-known detection equations and tracking algorithms. None of the more sophisticated techniques employed in the ODAP--such as Bayesian analysis or Von Neumann-Morganstern Utility Theory--are used in the TRIDENT aids.

3. One of the major problem areas involves the designing of aids to interface with the existing sources of data. Figure IV-4 illustrates the wealth of data used in calculating the detection areas. In developing the aids, the practical problems associated with interfacing the aids appear to overwhelm any theoretical considerations.

These circumstances illustrate why it is so difficult to develop operational aids in isolation and then to apply them in an operational context. The data that are available, their format, and indeed the way in which the commander uses the data are peculiar to the operational setting, i.e., the structure of the aids depends on the specific characteristic of own ship, the anticipated targets, and the form and availability of data.

4. Another major problem area in developing the aids lies in what to display and how to display it. Basically, the operators are saturated with information; they need a filtering process for reducing the quantity of information with which they must work. On the other hand, they want access to all information. They are extremely reluctant to have information within the

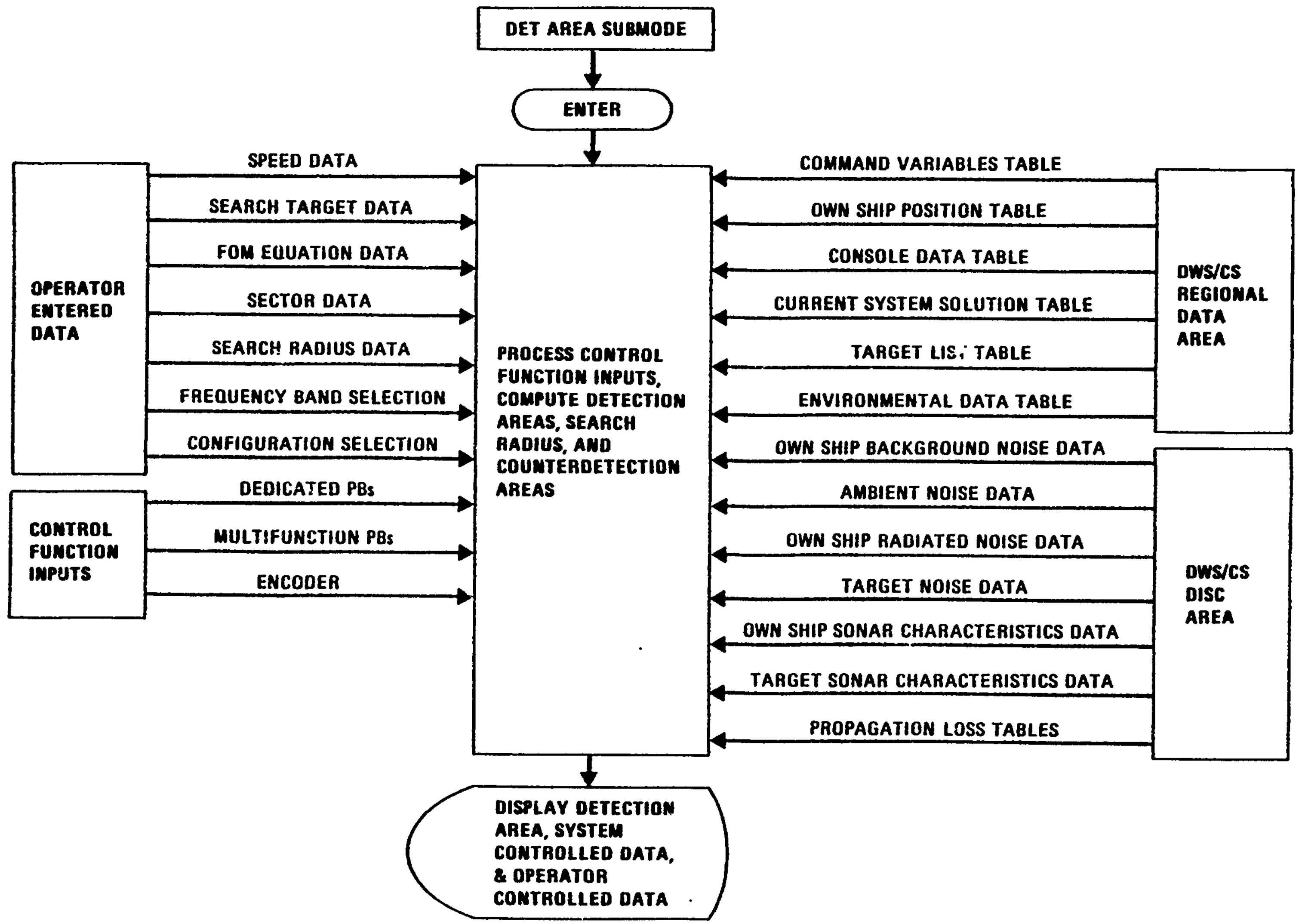

FIGURE IV-4. FLOW DIAGRAM INDICATING DATA REQUIRED TO COMPUTE DETECTION AREAS system that is not at their disposal. These seemingly conflicting goals were also encountered in VTS and SIMTOS, where they were satisfied through the use of a hierarchical data structure, which allowed an operator through specific requests to the system to access data at any level of detail he chose.

The operators also have an extreme reluctance to allow decisions to be made automatically. They want their workload reduced but not their decisionmaking responsibility. The three aids described in detail here all have this characteristic. They present the information but leave the making of the actual decision to the operators.

D. DECISION STYLE

As discussed in the last section, there is considerable latitude in what one selects for display with the decision aids and in how one chooses to display it. This is evident from examining any of the three decision aids described here. For example, the representation of Figure IV-1, in which regions where the probability of detection exceeds 50 percent are shaded, could be replaced by a set of constant probability of detection contours. One contour might represent the 10-percent probability of detection contours, the next the 20-percent contour, and so forth. Which of these formats is more appropriate can be determined to some extent by how accurately it is necessary to know the probabilities in order to effectively devise search patterns. But more important is probably the decisionmaker's style. Some decisionmakers require very detailed information to make a decision; others require only an overall assessment of the situation. The more detailed information just gets in their way.

The differences in "decision style" place a substantial burden on system designers and may result in dramatic increases in both the cost and time required to develop a system. In TRIDENT, for example, the frequent turnover in Naval personnel could result in a significant restructuring of the decision aid program. The new personnel have had different experiences, think in different ways, and have different values. They, therefore, likely differ in what they feel is suitable in a decision aid.

The most comprehensive and useful discussion of "decision style" we have seen was done by Honeywell Systems and Research Center for the Army Research Institutes SIMTOS program (see Chapter V). Honeywell discusses "adaptive" decision aids, which adapt to the decision style of the user, and "normative" aids, which are not adaptable and probably correspond most closely to the decision style of the system engineer.

Honeywell had developed a three-dimensional characterization of a prototype decisionmaker for use in developing adaptive decision aids. The prototype decisionmaker is characterized as abstract or concrete, logical or intuitive, and active or passive. The abstract decisionmaker, or more precisely the decisionmaker who exhibits the abstract rather than the concrete characteristic feels at home with symbolic displays; the concrete decisionmaker, with English language presentations. The logical decisionmaker prefers a hierarchical structured data base, so that he can systematically and methodically analyze the data. The intuitive decisionmaker prefers to see an aggregated characterization of an engagement so that he can rapidly infer what is taking place and quickly arrive at a course of action. The active decisionmaker, presented with a keyboard and a display, leaps in and makes use of all the capabilities the system has to offer. The passive decisionmaker sits back and quietly observes the information presented to him. He prefers to see a lot of information in the basic display, automatic prompting, and the like.

As this short discussion indicates, the decision aid structure that appeals to a particular decisionmaker and with which he can work most effectively varies with his style. The source of many of the problems that arise in the development of decision aids appears to arise from this diversity of decision styles. This suggests that the development of adaptive decision aids appears to have advantages not only in an increased acceptability of the aids but in increased effectiveness and, in the long run, in the time and cost required for development.

E. SIAC/SSN DECISION AID CONFIGURATION

Our discussion thus far in this chapter has been restricted to the characteristics of individual decision aids. There are also additional topics that pertain to the acceptance and utility of decision aids that could be usefully addressed. The question of changes in organizational structure of the commander's staff is one topic of interest. This topic has been addressed by ODAP. Another topic of interest relates to the configuration of the decision aids within the command center. This topic will be addressed here. We are particularly interested in demonstrating the very close relationship between the configuration adapted for the aids and the operational situation in which the aids will be employed.

We will briefly describe the approach taken in the SIAC/SSN (Submarine Integrated Attack Center) program to configure the decision aids within the Attack Center of the SSN 700 class submarines to optimize their usage by the commanding officer. Many of the aids for the SSN 700 class submarine are similar or identical to those for the TRIDENT.

The objective in configuring the aids in the Attack Center of the SSN were (1) to position the aids so that the aids with the greatest use were nearest the commander; (2) to position those aids that would be used together or sequentially near one another; and (3) to minimize the number of displays required. The achievement of the final objective required a determination of which aids required separate displays and which aids--using a window concept, for example,--could be simultaneously shown on a single display.

The approach used to determine the arrangement of the aids was to devise three "typical" scenarios (in the SIAC/SSN program they were referred to as operational scenarios) and then observe in a simulation the sequence of activities a commander followed in conducting the activities required by the scenarios. The three scenarios used were:

- The submarine proceeds from transit depth to periscope depth and back to transit depth. The activity is performed by the OOD who must communicate with the commanding officer, who is not in the Attack Center.
- The submarine is engaged in a non-aggressive barrier patrol. The activities involve primarily the surveillance function with emphasis on search, track, identification, target motion analysis, and communications.
- The submarine launches its weapons against a designated target. Prelaunch and postlaunch tactics are considered for the submarine. Emphasis is on environmental conditions, search, target motion analysis, approach, geographical situation, attack, weapon employment, and evasions.

Each of these scenarios requires an increasing number of activities. As a group they provide a reasonably comprehensive picture of the normal functions of the commander (OOD).

For each scenario a surprising number of activities are required. In the first scenario, for example, activities range from simply assessing the navigational situation to examining environmental and search data, to making course changes required to check the sonar blind zone astern, to communicating requests for performing particular activities to the commanding officer, to visual searching of the surface using the periscope, to monitoring of sonar source contacts, and to the performing of the activities necessary for return to transit depth.

Equipment involved in these activities includes such items as periscope bearing/range indicator, weapon control console, plotter, low light level television, chart table, fathometer, and radar and sonar display equipment.

Once the scenarios are designed and the simulations conducted and observed, the subsequent analysis is straightforward. As a first step, sequence diagrams are constructed that show movement of the commanding officer from area to area and equipment used in each area while performing a given activity. From the sequence diagrams histograms can be constructed showing for each or all three scenarios, the number of accesses to each item of equipment, the number of times that pairs of equipment are used in sequence, the number of times pairs of equipments were used together (simultaneous usage), and the percentage of time one display, two displays, etc. were simultaneously in use.

With this information--gathered from close observation of operations--efficient decision aid configurations can be devised.

The important point here--as it has often been elsewhere in the report--is that to effectively develop an operational system one must be in close touch with the operational situation. Without such contact it is nearly impossible to develop a successful system.

F. SUMMARY

In this chapter we have used the TRIDENT to exhibit the present (or near-term) status of decision aids in operational systems. We found that for the aids the most difficult problems were concerned with what to display, how to display it, and how to integrate the aids into the existing command and control structure. For each of the aids we also found the level of mathematical sophistication was substantially less than for the aids under development in the ODAP. In this chapter we also examined the configuration of the decision aids within a command (attack) center. We found that a solid familiarity with the operational situation was necessary in order to develop efficient decision aid configurations.

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V. SIMULATED TACTICAL OPERATIONS SYSTEM (SIMTOS)

The Simulated Tactical Operations System (SIMTOS) was developed by the Army Research Institute to assist in the development and study of computerized tactical command and control systems. It differs from systems developed for operational deployment, such as those considered in earlier chapters, in that it is a research tool intended for the study of data base organization and processing, decision aids, and the more general problem of human-computer interaction in tactical C^2 systems.

The approach taken in developing SIMTOS and the lessons learned in using the system should be of particular interest to the ODAP. The ODAP is currently setting up a simulation system at the University of Pennsylvania for the purpose of testing and evaluating the decision aids under development in the program.

A. BACKGROUND

In the late 1960s, a collection of off-the-shelf hardware was assembled and installed in selected 7th Army headquarters in Europe as part of an evaluation of the role of automation in tactical commands. ARI participated in the evaluation of many of the human factors aspects of the system. Many problems were uncovered as the system evolved, and though verifying the utility of automation in an operational environment, it was clear additional effort would be required for detailed system definition and requirement specification. The hardware was sent to Ft. Hood where it served for several years as a test bed for continued system development. In parallel with their participation at Ft. Hood, ARI began the development of SIMTOS to serve as a man-in-loop research vehicle which would permit controlled research on the human aspects of the use of computers in a tactical environment without undue confounding of variables and other practical constraints imposed by a field-test environment. SIMTOS has undergone continuous development and use throughout the 1970s.

B. CHARACTERISTICS OF SYSTEM

SIMTOS simulates an attack of a Warsaw Pact Combined Arms Army on a U.S. Army division in the Hof Gap area of the Central European theater. For the simulation an individual player assumes the functions of the G-3 (operations officer) and also some of the functions of the commanding officer. He may play either the offensive or defensive role. The simulation itself plays the role of the side--U.S. or Warsaw Pact--not played by the subject. The attack itself is divided into a planning phase and an execution phase. During the planning phase the G-3 performs such functions as the prepositioning of forces, the determination of force boundaries, and the assignment of firepower (tank company A to brigade B). During the execution phase, he performs such functions as the commitment and withdrawal of forces and the direction of artillery fire (strictly speaking, a function of the artillery officer).

All combat activity is played by the simulator. Combat algorithms are included to describe force movement, attrition, and tactical decision making. A decision to fire, for example, is based on whether a "circle of influence" associated with a friendly force element overlaps an enemy force element.

Hardware for the simulator includes a CDC 3300 computer and two CRT displays.

In the development and subsequent use of SIMTOS, the greatest attention has been given to the content, structuring, and processing of the data base for the system. The guiding principles in developing the data base were (1) <u>to include information a commander might receive from his staff</u>, and (2) <u>to organize it in a manner that simulates the commander</u>

speaking to his staff. The application of these principles led to a hierarchical data base structure. The highest level in the hierarchy corresponds to the commander's staff officers--personnel, intelligence, operations, logistics, and so forth. At the next level, under intelligence for example, are order of battle data and under it information on the strengths and dispositions of the forces.[1]

The SIMTOS designers have devoted considerable effort to decision aids that assist in processing the data base. Since the number of levels in the data base may reach 10 or 11, and a user must proceed level by level down the hierarchy to reach a particular data element, many of the aids are directed at simplifying and speeding up this data retrieval process.

One of the simplest aids is a natural consequence of structuring the data base along the lines of the commander's staff. Data at the upper levels are aggregations of more detailed data at lower levels of the hierarchy. For example, the total number of forces in a division are at one level, whereas at the next lower level the number is broken out into the number of forces in each brigade. Thus, data of most general interest is found at the higher levels of the hierarchy. Deeper penetrations into the hierarchy would generally be made when, in examining the data at one level of detail, a player decides he wants a more detailed breakdown and proceeds one step deeper into the hierarchy. The player would, therefore, seldom need to jump directly to a lower level of the hierarchy.

More formal aids also have been developed to simplify access to the data base. One of these uses preassigned indices to anticipate likely entry points in the data base; a player simply specifies an index and a jump is immediately made by the system to the desired access point. A more sophisticated version of the aid uses a dynamic indexing scheme; when an initial entry is made by the player to an access point, an index is automatically

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[1]The hierarchical data base structure described here is reminiscent of the indexed sequential file method used in data management systems on most third generation computers.

assigned by the system to the point. Then for future entries the player need only specify the assigned index and he will be automatically transferred to the desired access point.

In addition to the two direct access aids, another access aid that is receiving attention in SIMTOS provides a map of the data base structure, so that a player knows where to look to locate particular information of interest. In its present form, a "transfer function" is used in lieu of a map. The transfer function may be selected at certain designated access points within the data base. Selection of the transfer function automatically transfers a user to another access point that has been predetermined to contain information "probably of interest" to anyone who found the data at the initial access point of interest.

The general structure of the data base exhibits a principle that has been strongly endorsed by everyone with whom we have spoken: a decision aiding system should have the property that a user can "disaggregate" the aggregated data normally prepared by a system to any level of detail he chooses, i.e., virtually back to the original raw data. Most system developers believe that this is a necessary characteristic of a system if it is to be successful.

Now let us consider the operation of the system. As we described earlier, the simulation is divided into a planning and an execution phase. In the planning phase the player assigns forces, force boundaries, and firepower. He does this by responding to multiple choice questions posed by the simulator. In determining force boundaries, for example, the simulator asks which of the three possible lines should mark the forward edge of his forces. The player selects one of the three options, and the simulator proceeds to pose additional questions until the planning phase is completed.

An additional feature that the developers would like to have in the planning phase is a capability for the system to make recommendations. For example, they would like the system to have a capability to recommend, based on likely targets and the environmental features, the type of artillery that should be assigned to a particular area. This feature, in which well-structured problems with "textbook" solutions are handled by the computer, should considerably improve the decision aiding capability of the system. It should permit the G-3 to have more time to devote to other problems.

In the execution phase the player makes decisions relative to the commitment and withdrawal of forces and the assignment of artillery. Both CRTs are used in this phase. One of the CRTs is used as a status board to keep the player apprised of the state of both the friendly and hostile forces. The status board has a matrix format with unit designators denoting the rows and units attributes such as strength and location denoting columns. When a change occurs, e.g., a change in the strength of unit A, a light associated with the unit flashes to inform the player of the change. The player may then elicit further information from the system on the mission and detailed status of the unit.

A potential limitation of the automatic prompting feature is that many lights may be lit at the same time and the system does not indicate which of them are the more critical. (Recall that for VTS if two collisions were imminent, the one with the shorter time to collision received the higher priority and was so indicated on the working display.) In practice, the lack of a priority scheme does not seem to be a serious problem, for the G-3 is constantly aware of which units are engaged and of how the overall situation is developing. Based on this knowledge and on his experience, he can generally infer which events are potentially more significant and examine these first.

In the execution phase the second CRT provides the G-3 with a capability to pose questions to the system of a prespecified form. For example, in targeting, the G-3 may specify that he wishes to fire at target A and would like a list of the specific weapons--based on their location--capable of firing at the target. The system will provide him with the list.

D. DISCUSSION

1. Measures of Effectiveness

For a system such as SIMTOS to be successful, the commanders in the field must be convinced that the system (or the concepts contained within the system) will assist them in making decisions better or more quickly. Frequently, however, selling a person with an operational background on the value of such a system is extremely difficult and sometimes impossible, for any deviation of the simulator from strict reality may be perceived as a fatal weakness of the system. The operationally-oriented person often cannot accept (or chooses not to) any approximate representation of reality.

In SIMTOS the problem is illustrated by the G-3, who plays in addition to his own role, those of the artillery officer and the division commander. As a consequence, a commander may conclude (or claim) that the differences between the real world and the simulation are sufficiently great that no credibility can be ascribed to the simulation.

For the system developer, the message is that he should make every attempt to make those aspects of a system that are readily accessible to operational personnel correspond as closely as possible to the real world, even if it seems to him unnecessary to do so.[1]

A second problem, which bears heavily on the credibility of systems like SIMTOS, is concerned with the selection of the subjects for the experiments.

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[1]Experience suggests that the more closely an analysis, model or the like approaches reality, the better prepared the analyst needs to be to discuss the implications of small deviations from reality. The operations personnel, feeling more at home with the subject matter, come "alive" in presentations and subject the analyst to much more careful scrutinization than when the subject is of a more theoretical nature, in which case, the operational personnel feel less capable of (or interested in?) examining the results more critically.

Operational personnel who have had experience in the operational setting in which the system would be used are not available for the experiments. In the case of SIMTOS, G-3s with operational experience in Europe are not available Their numbers are very limited and they are being groomed for higher level positions. Hence, one is left with a sense of uneasiness that factors critical to the successful operation of a real tactical operations system have not been fully taken into account in the simulation. Under such circumstances, the best one can do is select the best personnel available. SIMTOS has done very well in this regard. In place of the actual G-3s they have used graduates of the Command and General Staff College, who appear to be excellently qualified for the experiments.

A final problem associated with measures of effectiveness concerns the use of scenarios. Considerable care must be taken in their construction, so as not to unfairly bias the evaluations of a decision system. In one set of scenarios used in experiments with SIMTOS, it was found that the results of combat were largely insensitive to specific decisions made by the G-3. The utility of the decision aiding system for these scenarios was therefore small.

The message for the system developer is quite clear: Although one wants to be assured that the scenarios one constructs are realistic, one also wants to construct them so that the outcome of the combat depends on the commander's decisions. Only in this way can the system be evaluated fairly.

2. Perfect Information

In Chapter II on the Standoff Target Acquisition System (SOTAS), we stressed the problems associated with the filtering and evaluating of information. We also pointed out that relatively little work had been done on these problems compared with the effort devoted to the development of efficient management information systems. SIMTOS provides us with an explicit example of this emphasis on information handling vis-a-vis information filtering and evaluations. As presently configured, the G-3 has full knowledge of the status of both forces. He is not faced with time delays in receiving information, incomplete information, misleading information, or uncertainties in the information he receives.

The developers of SIMTOS recognize the limitations that working only with perfect information imposes on their studies, but feel that much can be learned about the decisionmaking process within these constraints. For example, their current goal is to determine what data a commander typically uses in making decisions. Their approach is to provide all the data a commander might conceivably use, to observe what data he actually uses, and then to use this information for structuring future data bases.

Although not yet implemented, the developers of SIMTOS have developed an approach for introducing time delays and uncertainties into the system. Their plan for handling time delays is to maintain in the system historical force status records extending back over one or more time periods. Although greatly increasing storage requirements, this approach will permit the system to display to the G-3 time delayed force status data, while at the same time continuing the "real time" development of the conflict. The developers will use standard techniques--e.g., the use of normal distributions and sampling procedures--to introduce uncertainties in the values of the force status variables into the system.

3. Data Base Preparation

One particularly troublesome feature of SIMTOS and other similar tactical operations systems is the large data base required and large amounts of time and effort required to prepare it. There is little problem for situations like the Hof Gap where one can essentially do the necessary preplanning and preparation essentially years in advance; but in a dynamically evolving war the requirements for continuing on the spot preparation of the data base would probably make a system like SIMTOS unusable. Much greater attention needs to be given to building a data base "on the run" and to using a partially filled data base.

Aids should be developed to provide information on what data is currently available in the data base, what needs to be added, and what conclusions can be drawn from the available data. In addition, decision aids, such as those under development for the ODAP, should be examined to assess their utility in the presence of limited data and to determine how they might be modified to be most useful in a data-limited situation.

4. Color Graphics

Although we were impressed by the overall system, we found the SIMTOS environment austere, in that two black and white CRTs, even when augmented by a large wall map, did not seem to give a user a sense of being in close touch with the battlefield. We were thus pleased to see ARI's work in color graphics, much of which will be integrated into SIMTOS.

The heart of the ARI color graphics system involves a conceptually simple but nevertheless difficult to implement concept. A color television camera is focused on a large multicolored wall map. The section of the map within the field-of-view of the camera is then projected on to the screen of a color television set. The position of the camera relative to the wall map is maintained automatically by the system. This permits the system to relate any point on the screen to the corresponding coordinates on the map. (The map is stored internally within the computer.) Thus, if an operator using a light pen designates a road junction on the screen, the system is able to relate automatically the point to the road junction on the internally stored map. This conceptually simple feature is responsible for many of the sophisticated capabilities of the color graphics system.

Two simple outcome generators were demonstrated for us using the color graphics system. The first was a network analyzer. This aid assisted an operator in moving combat units to various objectives, so as to minimize the overall time of transit. After the operator selects an area of the map for examination, the aid automatically superimposes the network of roads in the area on to the map with different classes of roads being designated by different color lines. Using a hook, the operator may add new roadways or delete existing ones and select initial positions for units and objectives for them to reach. The analyzer then automatically selects and displays routes for the units to follow in order to minimize the times to the objectives. If the operator finds a particular solution unacceptable, he may add or delete additional roads and rerun the algorithm.

The second outcome generator demonstrated for us was a center of mass generator. A set of observations of vehicle movements--color coded according to time of observation--was displayed on the screen. The operator selected an observation time and drew a "fence" around a group of observations that appeared to form a fairly natural grouping. The system then found the center of mass for these observations. The operator then repeated the procedure for a later time and for a group of observations that looked as if it might represent the same grouping. The system then found the center of mass for these observations. Proceeding in this manner, the operator plotted and projected the route of the force. After the operator had examined several groupings, it became apparent that the observations corresponded to a large force approaching and deploying for a river crossing.

The addition of color graphics to SIMTOS would largely remove our concerns about the present austerity of the system. As a first step, a multicolored map displaying status and progress of the battle could be added to the system. The type of forces, the age of the data, and the like could be differentiated by color coding. Using the hook, the operator could move forces about the battlefield to assess the attractiveness of possible redeployments. It would then also be possible to develop much more powerful analytical tools. For example, once uncertainty is introduced into SIMTOS, an operator could use the system to explore candidate strategies for his forces. He would make his best estimates of the locations and strength of his and the enemy's forces, ascribe an objective to the enemy--e.g., the taking of a bridge--and then have the system play the strategies using his estimate. After he has explored a few candidate strategies, he would select one for his actual strategy. The system would then play his strategy against the actual disposition and objectives of the enemy forces.

This type of procedure would thus provide a vehicle for exploring the impact of uncertainty on the decisionmaking process.

With these additions, it seems to us that SIMTOS will provide a powerful tool in the development of tactical operations systems and perhaps contribute substantially to the training of officers.

E. SUMMARY

The design, development, and implementation of SIMTOS provide an excellent case study of the structuring and processing of a data base for use in a tactical operations system. The hierarchical structure, which simulates an officer speaking to his staff, is particularly attractive. When augmented by the color graphics, SIMTOS should provide a powerful research tool for studying many of the problems that arise in the development and use of tactical operations systems.

F. SOURCES

Dr. Stan Halpin, Army Research Institute, is in charge of SIMTOS development. Documentation includes the draft report: <u>Development and Application of Decision Aids for Tactical Control of Battlefield Operations</u>, prepared by Honeywell Systems and Research Center for ARI under contract DAHC-19-75-C-0008, UNCLASSIFIED.

VI. NAVY SURFACE SHIP COMBAT DIRECTION SYSTEMS

In this section, we discuss the combat direction systems employed on U.S. Navy surface ships. The term "combat direction system" refers to that portion of the combat system of a ship concerned with the collection, transmission, processing and display of information. The Naval Tactical Data System (NTDS) is an important element of most combat direction systems.

The combat direction systems are of considerable importance to the ODAP, for they are the source of a large part of the tactical data available to the commander. Furthermore, combat information systems are the area in which most commanders and their staff will have had prior experience in automated data processing.[1]

A. BACKGROUND[2]

The primary function of a combat direction system is to provide the commander with the information he needs to maneuver his ship and to employ its weapons in a combat environment. Prior to World War II this function was performed by the commander himself with the support of a limited staff. With the vast increase in the rate of data input associated with the

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[1]A number of aspects of combat direction systems of interest to the ODAP can be discussed only at the classified level. For those readers with appropriate clearances, we recommend Reference 1--Command and Staff Manual for Combat Direction Systems (U)--for a fuller treatment of combat directions systems than we can present here.

[2]Reference 2 is the primary source for the material in this section.

scientific developments of World War II, coupled with the changing nature of the threat, the function was assigned to a Combat Information Center (CIC). Recently, many functions of the CIC have been automated.

The NDTS was initially developed to improve the data communication within a ship, i.e., between CIC and the weapon control system. It also provided computer assistance for manual radar tracking. Digital and teletype data links were subsequently added to NDTS to provide a capability for transmitting data between ships. During Vietnam operations, sufficient tactical data was transmitted that a task force commander, located on a ship more than 100 miles from shore, could control the air battle over the mainland. The array and presentation of the data was sufficiently impressive that some ship commanding officers actually left their traditional battle station on the bridge to work in the CIC.

The need for a highly automated combat direction system is becoming increasingly important as a requirement develops for simultaneously handling multiple targets and for a short reaction time response capability to counter the developing missile threat.

B. SYSTEM DESCRIPTION

An unclassified description of the characteristics of the combat/combat-direction system currently being installed on DLG-28 Class guided missile cruisers is contained in Reference 3. This combat direction system is representative of recent systems installed on surface ships. Block and flow diagrams for the system are shown in Figures VI-1 and VI-2. The major information processing elements of the system are:

1. <u>The Automatic Detection and Tracking System (AN/SPS-48C)</u>

This system represents a major improvement over previous systems of this type. In previous systems, an operator manually detected radar

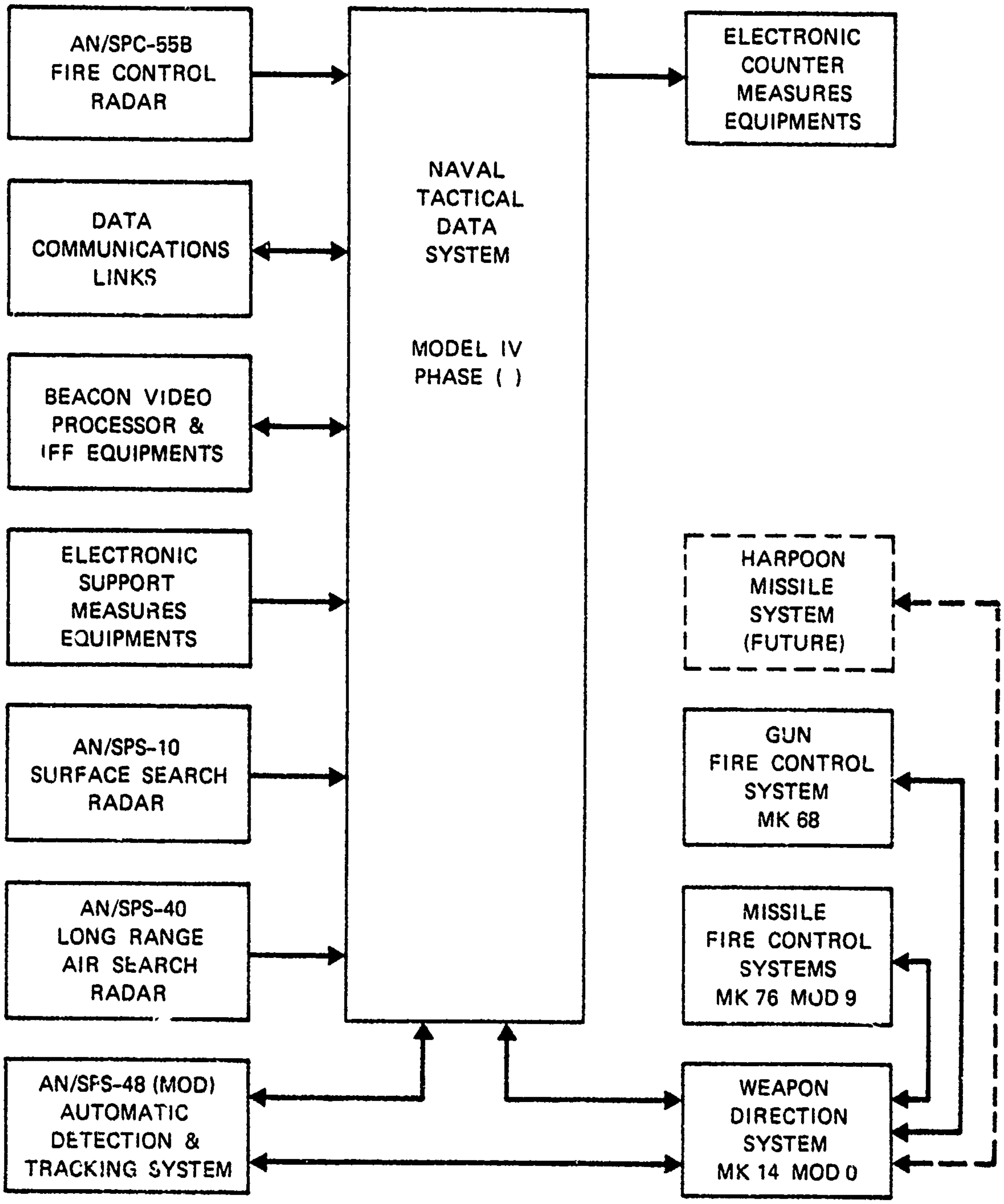

FIGURE VI-1. GENERAL BLOCK DIAGRAM OF DLG-28 CLASS COMBAT SYSTEM

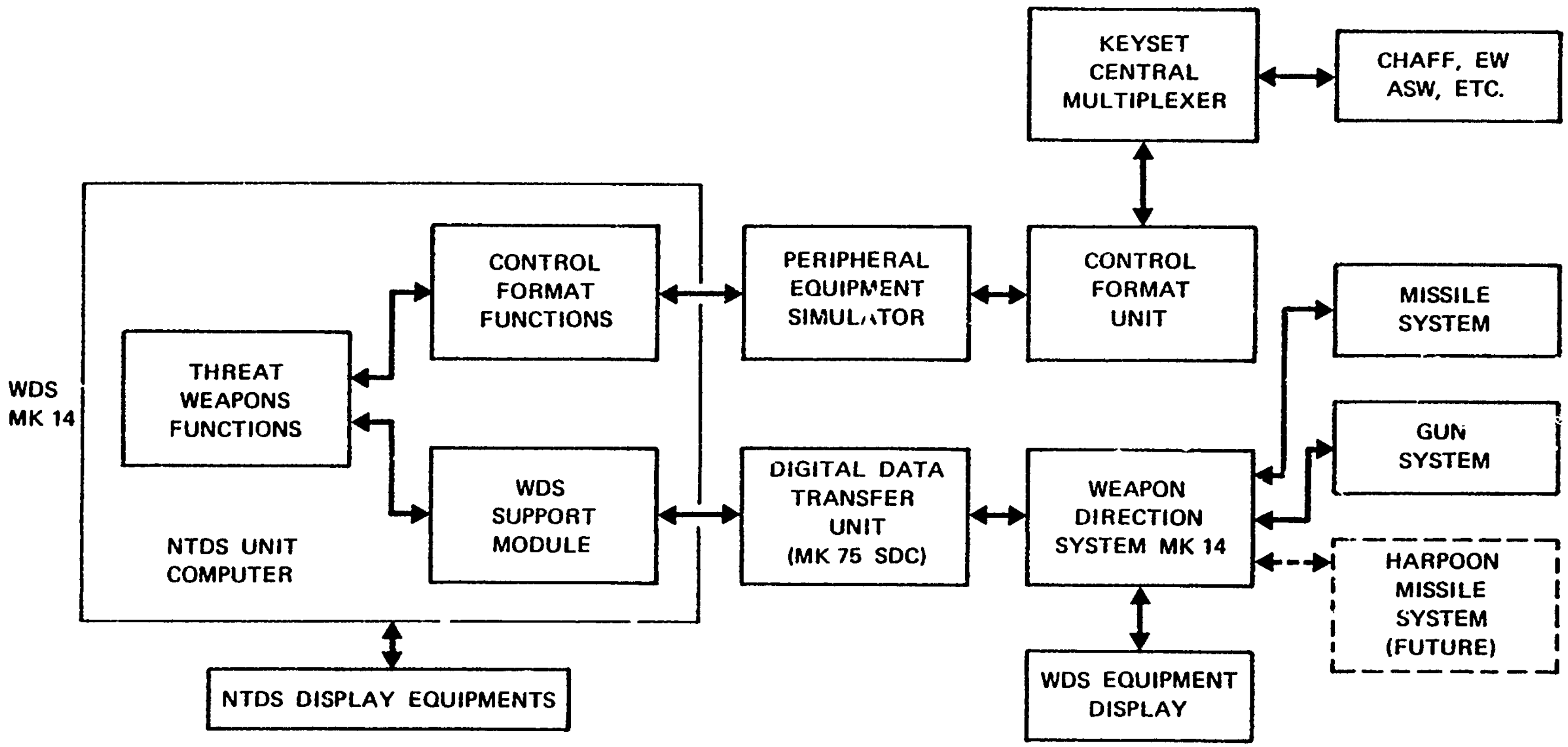

FIGURE VI-2. COMBAT SYSTEM ELEMENT INTERFACES targets and, with limited computer assistance, maintained target tracks. The AN/SPS-48C system:

- Automatically processes radar video returns to establish the presence of targets within its volume of surveillance responsibility
- Measures and stores target position coordinates for all target detections
- Initiates and updates target tracks to assist command and control in target definition and evaluation
- Provides estimates of target velocity components
- Uniquely identifies each track item for subsequent correlation processing
- Supports decision processing to aid in the rejection of false targets due to noise, RFI and clutter.

2. <u>The Naval Tactical Data System (NTDS) Model IV Phase 0</u>

Many versions of NDTS have been developed. The system is often tailored to individual ships and is subject to frequent revisions. The NDTS scheduled to be deployed on the DLG-28 in the 1977 time period contains the following elements:

- Information processing and storage equipment to support target definition, threat evaluation and response decisions
- Display equipment to present processed information to command elements and to support implementation of their decisions
- Data conversion equipment to format incoming data for central processing equipment and to format outgoing data to meet user requirements
- Data communications equipment to exchange information with other units of the fleet
- Computer programs to provide for rapid information processing and to support complex man-machine interactive operational requirements.

3. <u>The Weapon Direction System (WDS) MK-14 Mod 0</u>

The DLG WDS includes a general purpose automatic data processing complex, general purpose display groups, and support software. It has the following capabilities:

- Target and missile information processing and display
- Engageability calculations for selected targets
- Resource sceduling for multiple engagements
- Missile communications for flight control
- General coordination of multiple weapon type responses to the threat environment
- General management of missile pre-launch and post-launch control operations and general management of gun system responses
- Direct sensor system to weapon system interface.

C. TRENDS FOR DEVELOPMENT OF FUTURE COMBAT DIRECTION SYSTEMS

Reference 4 defines requirements for combat direction systems for general purpose forces. The following quotation discusses the role of automation in future systems.

> The scenarios commonly cited for possible naval conflicts include situations of imposing complexity. Faced with the possibility of nearly simultaneous raids of surface, sub-surface, and air launched anti-shipping missiles (ASM), naval task groups are forced to rely upon coordinated defense so that sensors, weapons, and platforms of the force may be employed with efficiency and mutual support. The very short reaction times required for proper defense against anti-shipping missiles have forced the Navy to improve early warning by expanding the area of surveillance, and to accelerate the command decision and weapon application process through the use of automation. Fortunately, growing technology, particularly digital technology has given us the potential to keep pace with these challenges. Successful application of digital technology to the weapons, sensors, combat directions, and communications of fleet units enables the design of systems which can enhance operational performance, reliability and flexibility. Digitalization of combat functions can, if properly implemented, facilitate reductions, both in manning and in the size, weight, and cost of hardware. There are, however, the following significant obstacles

which hamper any program to effect a sweeping implementation of digital technology.

a. Resource Constraints. The number of possible applications for digital integration and automation exceeds the industrial and fiscal resources available. Faced with the prospect of continuing fiscal austerity, the Navy has adopted a "design to cost" philosophy, embracing both acquisition and life cycle cost categories, to ensure that our scarce resouces are channelled into those applications which can demonstrate the highest payoff. In this fiscal climate, combat systems and combat direction systems must be designed to a standard of adequacy, rather than maximum capability.

b. System Complexity and Risk. Overly ambitious employment of "nice to have," rather than essential integration and/or innovative programming techniques can impose substantial risks to program costs and schedules and should be avoided. Software development for combat system processors can often become the critical path of ship construction and conversion programs, particularly if contractual aspects of software are not adequately treated. Programming complexities encountered in integrating new systems where standardization and configuration control is not or has not been effectively realized often pose substantial obstacles to the process of updating combat systems.

Reference 4 also contains the following points of significance to the ODAP.

- Systems shall be austerely designed but with allowance for future improvements to meet legitimate emergency requirements.
- Critical appraisal of digital data link information flow is required to insure that essential information is available for display to command, that the system design provides the necessary selectivity and flexibility, and that the information displayed does not exceed the capability of the user to absorb and evaluate the information.
- Automation of subsystem functions and integration of subsystems should be accomplished where the mission is essential, but discipline should be exercised to keep the combat system as simple as requirements permit.

D. SUMMARY

The nature of the current and projected threat to U.S. Navy surface ships requires the continued expansion and automation of present combat direction systems and their fuller integration with combat systems. Because of the requirement for a high level of system effectiveness, constraints on available resources, and the Navy's traditionally evolutionary approach to system development, a carefully planned and closely controlled program may be anticipated. Combat direction systems thus provide a fertile area for the application of the decision aids developed by the ODAP.

Future commanders and their staff can be expected to have familiarity with automated data processing through their experience with combat information systems. This suggests that aids that tend to fit in well with combat direction systems or appear to be reasonable extensions of them may be the most readily acceptable to a commander and his staff.

E. SOURCES

1. Commander, Naval Sea Systems Command, Command and Staff Manual for Combat Direction Systems (PD(A)-06165 (U), 76-052, 10 November 1976, CONFIDENTIAL.

2. Wayne E. Meyer, "The Combat Systems of Surface Warships," United States Naval Institute Proceedings, Volume 103, Number 891, May 1977, UNCLASSIFIED.

3. Fleet Systems Department, The John Hopkins University, Applied Physics Laboratory, Command and Control Functional Requirements for DLT-28 Class Ships with Weapon Direction System MK-14 Mod 0, FS-75-005, January 1975, UNCLASSIFIED.

4. Chief of Naval Operations, Configuration of Combat Direction Systems for General Purpose Forces, OPNAV Instruction 770.1, 31 August 1973, UNCLASSIFIED.

Note: Although Classified sources are referenced, only unclassified data from these sources were used in the preparation of this report.

VII. ARMY TACTICAL DATA SYSTEMS

Within this category are systems that support the Army in the area of tactical command and control. Included are:

- Tactical Fire Detection System (TACFIRE)
- AN/TSQ-73 Missile Minder
- Tactical Operations Systems (TOS)..

Of these systems, TOS is the primary interest in this study because it is intended to provide operational decision aids to commanders. The other systems are described briefly for the purpose of showing the types of tactical data systems developed by the Army.

The development of all of the systems listed above was seriously hindered by difficulties in determining user requirements. The TOS development history will be discussed as an example.

A. TACTICAL FIRE DIRECTION SYSTEM (TACFIRE)

TACFIRE is the Army artillery equivalent of the Navy combat direction system. TACFIRE is described in Reference 1 as:

> . . . a completely integrated system of tactical computer elements located at the fire direction centers of Active Army field artillery battalions, field artillery groups, division artilleries, and corps artilleries which will provide for automatic transmission, receipt and computation of firing data. Field planning, processing of artillery target intelligence, preliminary target analysis, fallout predictions, distribution of meteorological data, and maintenance of ammunition and fire unit status. TACFIRE will be interoperable and interface with the Tactical Operations System (TOS) and possibly with

> other Army Tactical Data Systems (ARTADS) within the conceptual framework of the Tactical Command and Control program as they are fielded. TACFIRE will use an integrated system of computers, local and remote input/output devices, digital storage and retrieval devices, display units and control consoles. TACFIRE will increase the effectiveness of field artillery fire support through increased accuracy, better and more rapid use of target information, reduced reaction time, and greater efficiency in the determination of fire capabilities and the allocation of fire units to engage targets.

Reference 1 indicates that TACFIRE has had limited procurement. It is currently in development and operational testing. Full-scale production is scheduled to begin in 1978.

B. AN/TSQ-73 MISSILE MINDER

The AN/TSQ-73 Missile Minder is a mobile, easily transportable, automated air defense control and coordination system. It will be used by the Army in the field to control and coordinate the fires of NIKE HERCULES and HAWK surface-to-air missile batteries. It provides airspace surveillance, target tracking, identification, display, and data link communications. An operational consideration for this system is an interoperability requirement for joint operations with Air Force units using the Air Force Tactical Air Control System, Control and Reporting Center Post (AN/TSW-91) and Marine units using the Marine Air Command and Control System (MACCS). The AN/TSQ-73 uses the same technology as TACFIRE and uses the same basic processor.

Reference 1 indicates that the system is scheduled for research and development completion during FY 1977. Production is scheduled for completion in FY 1979.

C. TACTICAL OPERATIONS SYSTEM (TOS)

Reference 2 defines the general functions of TOS as:

> . . . an on-line real-time automatic data processing system designed to:
>
> - Provide information to the commander and his staff at each echelon of comma.. :pon which estimates, plans, and decision will be based.
> - Assist in the analysis of courses of action and in the conduct of operations.
> - Provide for the display of information for staff planning, coordination and command decisions.
> - Reduce the reaction time of the command and improve the accuracy, timeliness, and dissemination of information estimates, plans, orders, and reports.
> - Enable the commander and staff to handle information and grasp the situation at an accelerated rate, thereby speeding decision-making and increasing control over tactical operations.
> - Permit the commander to act rather than react. As the system approaches real-time operations, its performance will be characterized by speed of information handling and processing and accuracy in operations.

TOS is currently in Advanced Development. It is scheduled for review by the Defense Systems Acquisition Review Council (DSARC) II in FY 1978 on entering Engineering Development. The history of TOS is discussed in the section which follows.

1. TOS Development History

The Army effort in tactical automatic data processing (ADP) began in 1955 with a study which identified and evaluated approximately 100 separate tactical ADP applications. In December 1961, a master plan for the Command Control Information System - 1970 (CCIS-70) program was published which defined the approach for introduction of field ADP.

A program review in 1964 lead to program reorientation and establishment of a new command for development (see 1965 on Table VII-1). The reoriented program provided for development and deployment of three related but semi-independent systems: TACFIRE, TOS, and CS_3.

A significant feature of TOS development is the large number of shifts in the responsibility of developing a tactical operations system. Table VII-1 shows the Army general staff and program management responsibility assignments since the start of the overall program.

TABLE VII-1

TACTICAL DATA SYSTEM RESPONSIBILITY ASSIGNMENTS

	GENERAL STAFF	PROGRAM MANAGEMENT
1955		U.S. Continental Army Command (USCONARC)
1961	Deputy Chief of Staff - Operations (DCSOPS)	
1962		U.S. Army Material Command (USAMC)
1963	Assistant Chief of Staff for Force Development (ACSFOR)	
1965		Automatic Data Field System Command (ADFSC)
1969	Assistant Vice Chief of Staff Army (AVCSA)	U.S. Army Computer Systems Command (USACSC)
1970	Assistant Chief of Staff for Force Development (ACSFOR)	
1971		U.S. Army Materiel Command (USAMC)
1974	Chief of Research, Development and Acquisition	

In the period of 1964 to 1969, a prototype tactical operations system (became EURTOS) was developed to evaluate the feasibility and desirability of TOS for the field army at the army level and below. The system was tested in Europe finishing in June 1969. The tests involved automating selected functions at the Army Corps and division levels. The hardware for the system was a van-mounted Control Data Corporation 3300 computer. The efforts were directed toward the development of a system for the Division and its subordinate units. In 1970, the EURTOS hardware and software packages were moved to Fort Hood, Texas to assist in the definition and development of requirements. The experimental system was renamed Development TOS (DEVTOS). After several tests were performed, the DEVTOS was evaluated as having accomplished its objectives and was phased out.

The current TOS program was started in 1970 after the EURTOS tests were evaluated. Requirement analyses were performed and a series of General Officer reviews conducted. The result was a decision to develop an austere TOS program called TOS Operable Segment (TOS^2). TOS^2 is intended to operate as a testbed for evaluation of concepts, software, and hardware. Specifications were prepared followed by initiation of software development and hardware procurement. The hardware is similar to TACFIRE hardware.

TOS is currently oriented toward collection, correlation, retrieval, and display of data concerning the status of friendly and enemy forces. However, as the following paragraph from Reference 3 indicates, specific functions have not been determined for TOS.

> In September 1974, TRADOC decided to recommend a reorientation of the TOS program (RTOS) from the initial concept described in the ATACCOMAP, published in September 1972, to an austere standalone computer system concept. The basic purpose of TOS remained: "To assist the commander and his staff in the decisionmaking process by providing information which is more timely, more accurate, more complete, and more available in a more useful form through automatic data processing." The key change was to limit the initial application of ADP assistance to the support of the Division Staff only, and provide for further investigations of system

growth potential in later phases. This phased introduction would identify the requirements for the initial application and present them to ASARC II/DSARC II for decisions on continuing TOS development, and procurement of an engineering development prototype. Subsequent phases would address the desired expansions of this stand-alone concept in terms of other echelons and other applications. HQDA indicated that the concept of the scaled down TOS could be supported. However, the description of TOS must await the results of testing and analysis of various alternatives.

2. Comments Concerning TOS Development

As is indicated in the previous section, specific TOS functions have not been determined. Discussions with individuals who have knowledge of the program provide these responses as to why the Army has not been able to define specific TOS functions:

- Desire to over-automate. Some degree of conflict exists between those who believe that work now being done by people could be better done by automation and those who believe that high degrees of automation are not achievable in a practical sense. Those opposed further feel that, if a high degree of automation were achieved, the resulting system would not be as effective as one making more use of human talents.
- Organizational problems. One specific example is treatment of uncertainty, e.g., should the tactical data system provide an assessment of enemy intentions or only describe enemy capabilities.
- Frequent changes in General Staff and program management responsibility. For any system, frequent changes would be disruptive. Since evaluation of the desirability of TOS capabilities tends to be rather subjective, frequent responsibility changes tend to increase difficulties in focusing on a specific set of TOS capabilities.
- Changing Army role. Consideration of what might be desirable in a TOS system started shortly after World War II. The Army has had three very different peacetime periods and two very different "police actions" during development of TOS requirements. Since the specifics of the Army mission changes, TOS requirements require update which adds another layer of difficulty to establishing specific requirements.
- Basic design problems. Even in the most benign development environment, it is not an easy task to define and develop an effective decision aid.

D. CONCLUSION

The difficulties encountered by the Army in defining system requirements for their tactical operations systems may in part be traced to their revolutionary approach to system development. TACFIRE, for example, is an entirely new and comprehensive system. It supercedes a much simpler system which employed a simple computer to generate weapon aiming data.

The Army's revolutionary approach to system development may be contrasted with the Navy's evolutionary approach. In developing combat direction systems, for example, the Navy's approach has generally been to automate functions that have been previously performed manually. Where new functions are added, they do not substantially differ from the functions that were performed before. The Navy's approach considerably simplifies the determination of system requirements and also simplifies the task of implementing the modifications to the system.

The ODAP by its very nature tends to be revolutionary rather than evolutionary. To avoid the type of problems encountered by the Army in developing their tactical operations system, the ODAP must exercise great care and extensive preplanning in developing the operational versions of their aids. Many of the recommendations in the chapter on VTS--particularly those relating to the need for close and extended interaction between system developers and users--seem particularly appropriate to the ODAP.

E. SOURCES

1. Department of the Army Deputy Chief of Staff for Research Development and Acquisition, RDT&E Programs and Budget Division, Descriptive Summaries of the Research Development Test & Evaluation Army Appropriation FY 1977 (U), CONFIDENTIAL

2. U.S. Army Command and Staff College, USACGSC RB 18-2, Descriptions of Selected Automatic Management Information Systems (MIS), 18 July 1974, UNCLASSIFIED.

3. Department of the Army, U.S. Army Tactical Command and Control Master Plan (ATACCOMAP) (U), August 1975, CONFIDENTIAL.

4. Colonel Birtrun S. Kidwell, Jr., AR and Lietenant Colonel Donald E. Hilber, FA, U.S. Army War College, Development of Army Tactical Data Systems User Requirements, 20 October 1975, UNCLASSIFIED.

Note: Although classified sources are referenced, only unclassified data from these sources were used in the preparation of this report.

VIII. OTHER ILLUSTRATIVE SYSTEMS

In this final chapter we will summarize two other decision aiding studies. The first is a review of the current decision aiding system in the National Military Command Center; the second, a mythical Naval software system. These studies put particular emphasis on problems encountered in software development. As a final topic, we will review an attempt to apply the Von Neumann-Morganstern Utility Theory to the problem of assigning aircraft to an attack on a Warsaw Pact airbase.

A. NATIONAL MILITARY COMMAND CENTER (NMCC)

The National Military Command Center is the primary center for exercising the command and control of United States military forces. Yet, as LTC Anthony F. Albright, who critiqued the current (as of May 1975) information system for the center, has stated, "There is no effective management information system in the NMCC which supports the decisionmaking function."

LTC Albright defines the role of an MIS as one of providing the right information in the right format at the right time. He believes the current NMCC system fails to meet this requirement:

- No capability exists in the system for displaying messages concurrently at multiple locations.
- Related information is often stored in separate files, thereby making it difficult for the user to locate the information he needs.
- Information retrievals are often in voluminous outputs making it extremely difficult to find specific data needed even after the system has produced the required report.

More generally, LTC Albright states:

> The design of the system was oriented toward system access by ADP programming-oriented personnel rather than operational users. The programs were oriented toward periodic, fixed format, large volume, output reports rather than the selective, quick response, condensed information summaries required by NMCC personnel today.

These observations by LTC Albright emphasize the need for <u>user-oriented</u> rather than <u>analyst-oriented</u> systems. If the user interfaces are not developed adequately, potential users are unlikely to employ a system. This was true for the NMCC system. According to LTC Albright, the selection of pertinent data and the assembly and summary of the data into meaningful information displays are currently performed manually rather than through the use of the automated system.

LTC Albright next defines what he feels are the requirements of an adequate system for the NMCC.

> The NMCC requires a dedicated, user-oriented, interactive MIS, which will be responsible to the center's information requirements during both daily (normal) operations as well as crises management operations.

The emphasis on both daily and crises management operations is of particular interest. These operational roles correspond to the planning and execution phases frequently discussed in the ODAP. LTC Albright further states:

> It is imperative that the MIS be used on a daily basis within the NMCC and not be reserved for crises management situations. In addition to making the MIS that much more effective because of its increased utilization, such an employment concept insures user familiarization and precludes the inevitable disasterous introduction of an unfamiliar information processing system during an actual crisis. This dual role, or flexibility of service, requirement which the MIS must satisfy is not unrealistic. Experience within the NMCC has shown that the operational information needs that arise during normal activities are quite similar in form and content to those which exist during a crisis.

LTC Albright next makes a number of general points concerning the selection of information for display in the NMCC:

- Sufficiency of information is not necessarily equivalent to volume of information. Or more simply put, it is not necessarily true that the more information you have the better off you are.
- Selection of information should be based on requirements, not on availability.
- In a crisis situation, there is a need for less information but for more carefully selected information than in normal operations.

LTC Albright recommends NMCC follow the current trend in computer system design:

> Advancing technology has . . . led to a trend toward using networks of minicomputers to perform specific functional tasks rather than employing large, more powerful, central computers . . . (minicomputers) have demonstrated extremely powerful performance in acting as front end processors and devices to interface CRT displays to C^2 systems . . . (the use of minicomputers to support integrated display techniques) would be in accord with the latest ADP industry thinking which favors the use of large scale computers to store and manipulate data bases and minicomputers to control the communication and display of processed data.

If NMCC were to follow this trend, LTC Albright suggests that plasma technology might then provide the key to the display of multisource data. A plasma "panel" would be located on the face of a CRT display. A viewer observing this CRT/plasma panel display would see two superimposed images, each of which is driven by a separate minicomputer. If this proves to be a viable approach, incompatible data stream would then never need to be physically combined at all, but could merely be superimposed on a common display for viewing by a decisionmaker.

B. THE MUDD REPORT: A CASE STUDY OF NAVY SOFTWARE DEVELOPMENT PRACTICES

MUDD--the Multisource Unified Data Distribution System--is a mythical software system whose development is chronicled in a report by David M. Weiss of the Naval Research Laboratory. The report is based on extensive interviews conducted by Mr. Weiss with people responsible for the development of software for the Navy. As its theme, it highlights the typical problems and pitfalls encountered in software system development and recommends procedures that would be useful to developers in avoiding them. The MUDD report complements this one in that it concentrates on the purely software problems of system development--design, structure, test and evaluation, maintenance, and the more general problems relating to assignment of responsibility and definition of requirements.

We will briefly describe the MUDD system, its origin and development, and then list some of the recommendations of the report. Many are similar to recommendations made in this report.

The events leading to the development of the MUDD system occurred when a submarine was reported cruising in an area thought to be free of hostile forces. In the course of reacting to the report, the cognizant commander requested information on the disposition of all forces in the area. The information was received far past the time it would have been useful. As a consequence of this incident, a committee was formed which spent several months studying ways of consolidating the collection and distribution of tactical information. It decided that a new system was required, which would consist of individually-tailored, information-gathering facilities aboard each ship, and a central land-based computer to maintain all tactical data and produce it on demand. The committee also decided intelligence data should be included in the system, in addition to tactical data, thereby requiring the system to communicate with other intelligence systems, some still in the predevelopment stages.

Before disbanding, the committee had one major decision to make: who should be responsible for developing MUDD. This proved to be a major problem. It was eventually resolved in the following way: the system divided naturally into an information gathering and an information distribution part. The information gathering activities were primarily concerned with fleet operations and were therefore assigned to one of the fleet groups. The information distributions activities were more closely related to intelligence groups. The committee therefore divided responsibility for the development of the system between the two groups. During the subsequent development of the system, many problems were encountered, including those described below:

- The developers were compelled to use the Navy's AN/UYK-7 computer. The only high-level language available on the system was CMS-2. FORTRAN, COBOL, ALGOL, and PL/1 were not available. The shore-based subsystem--known as the Data Use and Maintenance System (DUMS)--was later forced to switch to the WWMCCS Honeywell computer. Since this computer did not have a CMS-2 compiler, all programming written up to that point had to be discarded and programming personnel retrained or replaced. Moreover, the support software was inadequate for development of the ship-based system which continued to use the AN/UYK-7 computer.
- The ship-based subsystem--known as the Ship Information Processing System (SIPS)--encountered extensive problems because every ship class under development had a different version of every major module in the system. Each required its own documentation.
- The contractor on SIPS was originally chosen by a low-bidder procedure which selected the (technically qualified) contractor with the lowest average cost rate per programmer. The contractor maintained his low rates by hiring three experienced programmer-designers at high salaries and a number of inexperienced programmers at low salaries. The experienced personnel eventually left the contract.
- The Critical Design Reviews (CDR) of the system were essentially just tutorials of the system. The CDR for the shore-based system lasted only about 3 hours. No really critical review was held. This led to extensive problems later in the development.
- In the test and evaluation phase, the end users of the system (who had not been consulted since the CDRs[1]), now that they had a chance to observe it in operation, wanted it modified. Those with the most complaints were the intelligence analysts and operational commanders. They were not receiving the data they needed. For example, an operational commander could easily obtain a list of

[1]Compare with the discussion of VTS.

all hostile ships which entered or left an area within the last week--information of particular interest to the intelligence analyst--but could not obtain a list of hostile ships currently in the area. This appeared to be a direct consequence of the division of responsibility for the system and the resulting lack of communication between the two groups.

The subsystem required extensive maintenance. After about 4 months, the level of effort stabilized at about 30 percent of the level required during coding. This was partly due to the large number of versions of the individual modules in the ship-based system. More significant, perhaps, was the interdependence of the modules and the lack of standarized interfaces between modules (so called, information hiding). For example, the developers of one module, knowing that the developer of another module had stored information they required at a certain point and form on a disk, would access it directly rather than through a standardized interface. Thus, changes in one module affected the performance of other modules.

As a consequence of these and other problems, the MUDD system incurred a time overrun of 100 percent and a cost overrun of 150 percent.

Mr. Weiss at the conclusion of his report on the MUDD system presents a number of recommendations for future system development. We repeat a number of them here.

- Unify life-cycle control of software. Development responsibility for a system should not be split and maintenance activity should not be independent of development activity. In particular, system maintainers should participate in the development cycle from requirements definitions to delivery. Separation of control over software during its lifetime leads to additional interfaces and inhibits feedback useful for preventing repetition of errors.
- Require the participation of system users in the development cycles from the time requirements are established until the time the system is delivered. MUDD users never saw the system until operational test and evaluation. Many of the modifications they then requested could not be implemented because the changes were too costly. Changes which are inexpensive and easy to implement at system testing time are often extremely expensive and difficult to implement after the software has been written.

- <u>Write acceptance criteria into software development contracts.</u> Both the contracting agency and the contractor then have a clear idea of the requirements the system must meet to be accepted. If the criteria are not clearly established in the contract, there may be a misunderstanding and a protracted delay for negotiation before the system is delivered.

- <u>Develop software on a system that provides good support capabilities.</u> If necessary, consider developing support software prior to or in conjunction with system development. Most support software is a good example of sharable software. The DUMS developers were considerably aided by the presence of support software, and the SDS developers were sorely in need of it. Support software included assemblers, compilers, operating systems, text editors, and management information systems.

- <u>Allocate development time properly among design, coding, and checkout.</u> Software development experience indicates that rough estimates for these phases are 40 percent for design, 20 percent for coding and 40 percent for checkout. Some of the variables involved are the nature of the project, the design models available for the project, and the experience of the designers. All developers should keep a file of past experience of the designers. All developers should keep a file of past experience in this area for future guidance. Since manpower-allocation estimates are based in part on the time estimates for the different phases of development, improper estimation can be quite expensive.

- <u>Use state-of-the-art design principles such as information hiding.</u> Large systems, such as the ship-based subsystem of MUDD, must be designed using principles that optimize the chances for producing reliable, inexpensive, maintainable software. The resulting design may even seem unnatural to designers accustomed to optimizing for efficiency. Ignorance of information hiding helped produce a MUDD system that was expensive, late, unreliable, and difficult (and sometimes impossible) to improve or maintain. The basic problem in MUDD was that each module took advantage of implementation decisions made in other modules. A change to one module then started a chain reaction of changes in other modules. Naturally, the larger the number of changes required, the lower the probability and the higher the expense of correctly implementing a modification to the system.

  The software design should isolate and insulate all areas where requirements are most likely to change. In particular, all interfaces with other systems over which the developers and users have no control should be transparent to the rest of the system. Data obtained from other systems can change in format in unpredicted and unheralded ways. Often the only recourse in such situations is to change the module which inputs the data. A change of this nature should not require a change to more than one module. This is an important instance of the need for information hiding.

- Critical design reviews should be active reviews and not passive tutorials. Sufficient time must be allowed to read design documents before the review, and the documents must be readable. Alternative design decisions and the reasons for eliminating them should be discussed. In addition no code should be written until the design is approved. The critical design review is the last and most important time to catch errors before coding starts. Once code has been written, any design change involves at least examining all existing code for the impact of the change and may involve discarding and modifying code. System progress is delayed during this process. Consequently the cost of a design change during coding may be 2 or 3 times the cost of the change before coding. The multiplier becomes larger the farther the system progresses in the development cycle.

- Ensure that a proper variety of test data is used. The differing MUDD experience between system integration and test and evaluation is indicative of some of the problems that arise when a system is incompletely tested. Support software capable of monitoring system tests and reporting on failure and on what code has and has not been tested is not coming into use. Test data can be generated by use of a simulator. Although testing cannot by itself be used to guarantee reliability, it will probably remain for some time to come as the basis for finding errors and inspiring confidence in the systems.

- Maintain current complete documentation. Documentation is an often neglected part of software development. In many systems, it is done on an after-the-fact basis and rarely updated. This may be because no one knows how to do it properly. Unreliable documentation forces the maintenance programmer to rely on nothing but code reading, a long and tedious process for his understanding of the system. Well-written documentation will have few redundancies and many cross-references; it will be tailored to suit the system being documented. One sure sign of danger is when coders use unofficial documents and produce the official ones only because of contract requirements.

C. ATTACKING HARDENED AIR BASES (AHAB)

The primary emphasis in this report has been on operational decision aids and decision systems. Attention has also been focused on systems like SIMTOS, which are simulators used to study the decisionmaking process in an operational setting, and on such semi-theoretical work as Honeywell's studies of decision style. Little attention has thus far been given to sophisticated mathematical techniques that appear promising for operational use. Partly, this is because much of the potentially useful work is or has been conducted by ONR and is described elsewhere. Partly, it is because much of the work must undergo a considerable amount of additional development to be operationally useful. Nevertheless, several interesting attempts have been made to apply sophisticated mathematical techniques to operational decision problems.

A particularly interesting and representative example of the application of mathematical aids to operational decisionmaking is the AHAB computer program, under the auspices of the United States Air Force Project Rand. AHAB represents an attempt to use Von Neumann-Morgenstern Utility Theory to assist tactical decisionmakers in planning an air strike against a Warsaw Pact airbase. It allows the user to explore the consequences of adopting a variety of tactics for attacking the airbase. Pertinent variables considered in AHAB are: (1) the number of enemy aircraft destroyed, (2) the number of aircraft shelters or hangarettes destroyed, (3) the number of hours the runway system is closed and (4) the number of friendly aircraft lost in the strike.

AHAB is a Monte Carlo simulation model. Repeated trials of an attack on the airbase are made with the outcomes of stochastic events on each trial--such as the destruction of a friendly aircraft--being determined by comparing a random number drawn from an appropriate probability distribution to a probability of kill, which is input to the model. The expected utility of the attack is calculated by averaging over the utilities of each trial. The model does not contain an algorithm for selecting tactics that maximize utility, but rather the user must explore the utility space by repeatedly running the model for alternative tactics. This does not limit the potential usefulness of the model or the concepts, however, for an optimization algorithm could always be added to the model.

The heart of the AHAB model is the Von Neumann-Morganstern utility function, which is used as an objective function or measure of effectiveness for evaluating alternative tactics by the commander. In this section we will assume the reader is familiar with the general idea of utility theory and we therefore plan only to indicate, using AHAB, how the theory is typically applied in practice. AHAB assumes the utility function is additive so that it may be used in this form:

$$U(x_1, x_2, x_3, s_4) = \lambda_1 u_1(x_1) + \lambda_2 u_2(x_2) + \lambda_3 u_3(x_3) + \lambda_4 u_4(x_4)$$

where the variables x_1, x_2, x_3, and x_4, refer in AHAB to the four variables discussed earlier, i.e., the number of enemy aircraft destroyed, the number of hangarettes destroyed, and so forth. The λ_i's are weighting coefficients representing the relative importance of the four factors.

Use of the additive theory greatly simplifies the determination of the utility function, because each of the four component utility functions can be constructed separately. Using the BRLT (Basic Reference Lottery Ticket) method, and considering, for example, the first utility function $u_1(x_1)$, set the value of the function to one at a value of x_1 corresponding to all enemy aircraft destroyed. This is the best possible outcome. Similarly, set the value of the function to zero for a value of x_1 corresponding to no aircraft destroyed. This is the worst possible outcome. Then determine from the decisionmaker what certain outcome--i.e., number of planes destroyed--is equally preferable to a lottery in which all planes are destroyed with a probability of 50 percent and no planes are destroyed with a probability of 50 percent. Assign this outcome a utility of 0.5. Continue this halfing process to the desired degree of refinement (in AHAB the program locates nine points in this manner). Intermediate values of the utility function are found by linearly interpolating between these points.

The procedure for obtaining the weighting factors w_i is equally straightforward. Let b_i be the best possible value for the variable i and w_i the worst possible value. Consider the four situations:

$$
\begin{aligned}
S_1 &: (b_1, w_2, w_3, w_4) \\
S_2 &: (w_1, b_2, w_3, w_4) \\
S_3 &: (w_1, w_2, b_3, w_4) \\
S_4 &: (w_1, w_2, w_3, b_4) .
\end{aligned}
$$

Note that

$$U(S_i) = \lambda_i .$$

Ask the decisionmaker which of the four situations he prefers. Suppose he selects S_4. Then ask him what level of x_4 makes (w_1, w_2, w_3, x_4) equally preferable to S_1. If he selects $\bar{x}_4$, then

$$\lambda_4 U(\bar{x}_4) = \lambda_1 .$$

Repeating the process for S_2 and S_3 yields three equations in four unknowns. Adding a normalization condition on the λ_is--which is equivalent to multiplying the utility function by a positive constant--allows the λ_is to be determined uniquely. This completes the determination of the utility function.

The use of additive utility functions imposes two potentially restrictive limitations on the flexibility of utility theory to reflect the decisionmaker's value system. These are commonly known as preferential and utility independence. In preferential independence the tradeoff between any two variables for constant utility must be independent of the value of any third variable. For example, the number of friendly aircraft a decisionmaker is willing to lose in order to destroy a given number of enemy aircraft may not depend on the number of hangarettes destroyed or the time the runway is out of operation.

Utility independence implies that the marginal utility of any variable is a function of that variable alone. For example, for this condition to be met, the loss in utility associated with losing a friendly aircraft must be independent of the number of enemy aircraft already destroyed. In general, the condition thus severely limits the use of the additive utility theory. In a situation like AHAB, however, where the attack is conducted against only a single airbase, involving only a small portion of the total forces of both sides, the limitation is probably not overrestrictive.

The AHAB model has not been tested in an operational environment but has been used principally as a research tool to explore the potential use of utility theory in decisionmaking. Air Force officers, who were shown the system, found the concepts attractive and felt that a more comprehensive model might have some practical significance. The model might, for example, speed up the decision process and produce more consistent results. Whether this is correct, however, remains an open question.

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Note: Although classified sources are referenced, only unclassified data from these sources were used in the preparation of this report.

SUPPLEMENTARY

INFORMATION

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MEMORANDUM TO DISTRIBUTION

Subject: Errata Sheet to System Planning Corporation Report 312

Reference: "An Investigation of Operational Decision Aids," written by Gary L. Lucas and Jan A. Ruff, dated 2 July 1977

The following changes should be incorporated into the referenced report.

Page

33 Replace paragraph 2 (line 10) with

Within the present Army structure, the intelligence branch is responsible for surveillance; the artillery branch, for target acquisition. Hence, the roles of SOTAS cross current organizational lines. Consequently, in developing SOTAS, continual review of existing procedures and practices for conveying information between organizational elements was needed to ensure that procedural delays could be eliminated and that the advantages of the automated system would be realized.

35 Delete from line 5

and the performance of the system decreased.

35 Delete from last 2 sentences

By being positioned behind the FEBA, it is relatively invulnerable to ground fire and because of the tracker,